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THE INFLUENCE OF DIFFERENT COLOR ENVIRONMENTS ON THE BEHAVIOR OF CERTAIN ARTHROPODS

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THREE FIGURES

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INTRODUCTION

The protective resemblances of various arthropods have long been subjects of interest to naturalists, and a host of observations have been made which bear directly or indirectly on such phenomena. There is no doubt that many of these resemblances

are beneficial to the animals possessing them, and it is quite generally believed at present that "natural selection has undoubtedly been the chief factor" (Kellogg, '05, p. 613) in developing most of the striking cases that have been recorded. Not only have the colors of numerous animals been shown to correspond very closely to those found in their natural environment, but many species are known to change their colors under certain conditions in a very striking manner, thus causing them to harmonize very closely with the background.

Notwithstanding the amount of evidence which has been accumulated along these lines, little attention has been given to the reactions of protectively colored animals with respect to their color environment. The experiments described in this paper were undertaken to determine, if possible, whether the reactions of arthropods to colored backgrounds and colored objects are such as to bring them into the best surroundings; in other words, do the reactions of protectively colored arthropods indicate that such animals realize that their coloration is advantageous on certain backgrounds, but not on others. No attempt was made to demonstrate color vision in these experiments, i. e., the perception of colors *per se*. The following animals were studied: A crayfish, *Cambarus propinquus* Girard; a caddis fly larva, said by Professor Charles T. Vorhies to belong to the genus *Neuronia* and probably to the species *postica* Walker; a spider crab, *Libinia emarginata* Leach; and a spider, *Misumena aleatoria* (Hentz) Emerton. The original experiments with these animals will first be considered and all general questions left for discussion later.

DESCRIPTION OF EXPERIMENTS

The Crayfish, *Cambarus propinquus* Girard.—In order to ascertain the effect of subjecting crayfishes to various color environments for long periods of time, twelve individuals were selected which were as nearly alike in color and size as possible (56 to 66 mm. in length); half of these were males and half females. Owing to the fact that two of the females died after the experiments were begun, only the males were used in testing reactions.

A pair of crayfishes was placed in each of the six rectangular glass jars used for the experiments. These jars measured

20 cm. in height, and their other dimensions were 12 cm. and 15 cm. respectively; they were kept about one-fourth full of filtered water, which was changed frequently. Each of the six jars was, except at the top, completely enclosed within a tightly fitting wooden box (called a "color box" in these experiments) which had been painted a particular color on the inside. One box was painted black and another white; the colors used in the others corresponded to the following shades in Klingksieck et Valette's "code des couleurs":* Red, 8; yellow, 128; green, 303; blue, 376. A cardboard painted like the inside of the box was supported three-quarters of an inch above each in such a way that though ventilation was permitted and light allowed to enter, the color environment of the crayfishes in each jar was all of one shade. Figure 1 is intended to represent the general plan of a color box.

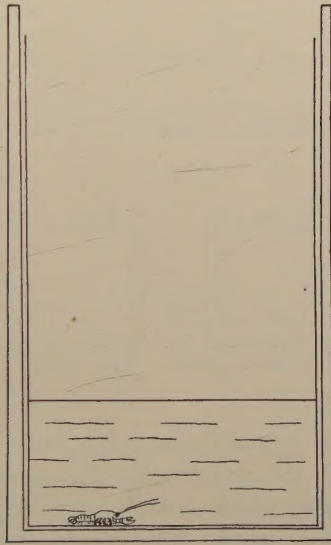


FIGURE 1—Showing plan of a "color box" containing a glass jar partly full of water.

The crayfishes were placed in the color boxes on December 10, 1908, and kept under observation until January 19, 1909. During this time most of the individuals gradually changed color slightly

*Klingksieck et Valette's Code des couleurs will be subsequently indicated by the initials, C. C.

so that they more nearly corresponded to their environment. The dark median stripe down the abdomen was more prominent in those individuals kept in the red and black boxes; those in the blue had a decided bluish tint; and those in the yellow were noticeably yellowish. Control animals of similar size and age, kept in open glass dishes did not show such variations. These results agree with those of Kent ('01) who made similar experiments on a related species of the same genus of crayfishes. Such color changes are apparently not uncommon among crustaceans and many more striking examples might be cited.

After the crayfishes had been kept for some time in the color boxes the next step was to ascertain whether such prolonged subjection to a monochrome environment would cause them

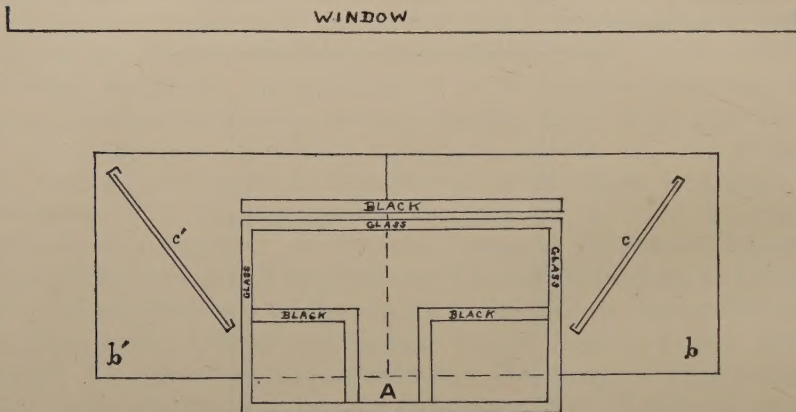


FIGURE 2—Ground plan of apparatus for testing the reactions of the crayfish to colors. A, runway where animals were placed; b, b', c, c', removable colored cardboards.

to move more often toward one color than another. This was tested by means of the apparatus shown in Figure 2. It consisted of a rectangular glass dish (10 cm. high, 40 cm. long and 24.5 cm. wide) fitted up so that an animal could be placed at the beginning of the runway, A, and allowed to move down it until it must choose between the two sides b and b'. The only difference between these sides was in the colored screens c, c' and the cardboards b, b' which could be changed at will. The glass dish was filled with filtered water to a depth of four centimeters during the experiments, and the whole apparatus

was covered above with a flat black screen which was placed over it immediately after each animal was introduced.

The tests consisted in giving each individual ten chances to choose between the color corresponding exactly to the tint by which it had been surrounded for some time (at b and c) and each of the five other colors used for the experiments (at b' and c'). In order to avoid fatigue the different individuals were used in

TABLE I

REACTIONS OF SIX MALE CRAYFISHES TO COLORS AFTER HAVING BEEN SINCE DECEMBER 10, IN A MONOCHROME ENVIRONMENT

No. of reaction		December 19										Total		December 31										Total		Grand Total	
		1	2	3	4	5	6	7	8	9	10	+	-	1	2	3	4	5	6	7	8	9	10	+	-	+	-
White vs.	Blue	+	-	+	+	+	+	-	-	-	+																
	Red	+	+	-	+	+	+	+	-	+	+																
	Yellow	-	+	-	+	+	+	+	+	-	+																
	Green	-	+	+	+	+	+	+	-	-	-																
	Black	-	+	-	-	-	-	-	-	-	+																
Total.....												23	27													23	27
Blue vs.	White	-	+	+	+	+	-	+	+	+	-			-	+	-	-	+	-	-	-	-	-				
	Green	+	+	+	+	+	-	+	+	+	-			-	+	+	+	+	+	+	+	+	-				
	Yellow	-	+	-	+	-	+	+	+	+	+			+	+	+	+	+	+	+	+	+	-				
	Red	-	-	-	+	+	+	+	+	+	+			-	+	+	+	+	+	+	+	+	+				
	Black	+	-	+	+	+	+	+	+	+	-			+	+	-	-	+	+	-	+	+					
Total.....												29	21											26	24	55	45
Green vs.	White	+	-	+	+	+	-	+	+	+	-			+	+	-	-	+	+	-	+	-					
	Blue	+	-	+	+	+	-	+	+	+	-			-	+	-	+	+	+	+	+	+	-				
	Yellow	-	+	-	+	-	+	+	+	+	+			+	+	-	-	+	+	-	+	-					
	Red	-	+	+	+	+	+	+	+	+	+			-	+	+	+	+	+	+	+	+	-				
	Black	-	+	-	-	-	+	+	+	+	+			-	+	+	+	+	+	+	+	+	-				
Total.....												24	26											24	26	48	52
Yellow vs.	White	+	-	-	+	+	+	+	+	+	-			+	+	-	+	+	+	-	-	-					
	Blue	+	+	-	+	+	-	+	-	-	+			+	+	+	+	+	+	+	+	+	-				
	Green	+	+	+	-	+	-	+	+	+	+			+	+	+	+	+	+	+	+	+	-				
	Red	+	+	+	+	+	+	+	+	+	+			-	+	+	+	+	+	+	+	+	-				
	Black	+	+	+	+	+	+	+	+	+	+			-	-	-	+	+	+	-	+	+					
Total.....												29	21											25	25	54	46
Red vs.	White	-	+	+	+	+	-	+	+	+	-			-	-	+	-	+	+	-	-	-					
	Blue	-	+	+	+	+	-	+	+	+	-			-	+	+	+	+	+	+	+	+	-				
	Green	-	-	-	+	+	+	+	+	+	+			+	-	+	+	+	+	+	+	+	-				
	Yellow	+	-	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+	+	+	-				
	Black	-	+	-	-	-	+	+	-	+	+			+	+	-	+	+	+	+	+	+	-				
Total.....												22	28											25	25	47	53
Black vs.	White	-	+	+	+	-	+	-	+	+	-			+	-	-	+	+	+	-	-	-					
	Blue	-	-	+	+	+	-	+	-	+	+			+	-	+	+	+	+	+	+	+	-				
	Green	+	-	+	+	+	+	+	+	+	+			-	+	+	+	+	+	+	+	+	-				
	Yellow	-	+	+	+	+	+	+	+	+	+			-	+	+	+	+	+	+	+	+	-				
	Red	-	+	+	+	+	+	+	+	+	+			-	-	-	-	-	-	-	-	-	+				
Total.....												22	28											26	24	48	52
Grand Total...												149	151											126	124	275	275

rotation and no more than ten successive reactions were recorded for any of them at one time. Possible errors due to a marked tendency of any individual to turn in a certain direction were avoided by interchanging the screens and cardboards, *b*, *c*, and *b'*, *c'*, after every five reactions. In recording reactions, animals which went toward the color corresponding to that of the box in which they had been kept were called "+"; those in which the crayfishes went toward some other color were "—". Two series of tests were made, on December 19 and December 31. The crayfishes tested had been, in both cases, in a monochrome environment since December 10. The results of the experiments are shown in Table I; they indicate no effect due to the prolonged sojourn of the crayfishes in a particular environment, for there were as many reactions toward other colors as the one by which the crayfishes had been long surrounded. Furthermore, Table II, which is based on the same reactions as Table I, shows that there was no striking difference in the number of reactions toward any of the colors used, i. e., no "preference" for any particular color.

TABLE II

NUMBER OF TIMES EACH COLOR WAS CHOSEN BY SIX MALE CRAYFISHES

	White	Blue	Green	Yellow	Red	Black
December 19	48	58	47	57	41	49
December 31	32*	41	45	41	48	43
Total	70*	99	92	98	89	92

To summarize, the experiments described show that though the colors of the animals may change to some extent, so that they more nearly resemble the background, the reactions of crayfishes to colored backgrounds are not influenced by a prolonged sojourn (21 days) in a monochrome environment.

The Spider Crab, *Libinia emarginata* Leach.—*Libinia emarginata* is easily obtained at Woods Hole and the writer

*The numbers in this column are smaller than the others because the male which had been in the white box died and, as is indicated in Table I, this animal, therefore could not be tested on December 31.

was able to experiment with it while occupying a room in the Marine Biological Laboratory during the summer of 1909. This species is of particular interest on account of its decorating habits. It takes various objects, such as bits of sea weeds, hydroid colonies, or in fact, almost anything that comes in its way, and sticks them on its back in such a way that it is very effectually concealed among the thick growths on the piles and sea bottoms.

This crab is especially favorable for testing the question of selection with reference to colored backgrounds and a series of experiments was performed with this point in mind. All the animals used were smaller than the adult size for the species, none of them measuring more than eight centimeters in length. The method employed was to clean the back of a crab with a brush and then put it into a dish filled with sea water; after a short time several pieces of colored papers were added so that a choice was offered between papers colored like the environment and those which were not. The dishes were cylindrical in form, measuring 15.5 centimeters in diameter and seven in depth; each was completely surrounded on the bottom and sides by a monochrome paper. The bits of paper were of uniform size (one by fifteen millimeters) throughout the experiments. The behavior of the crab toward the colored papers was observed from time to time for about twenty-four hours. Under such circumstances, the crabs seldom failed to put some of the papers on their backs, and their interesting decorative maneuvers were often watched by the writer. Two kinds of experiments were tried; (a) those to test black vs. white discrimination, and (b) those in which a variety of colors were involved.

(a) *Black vs. White Discrimination.* *Experiment 1*—July 6, 3.30 p. m., a clean *Libinia* was put on a black background. 3.35 P. M., ten pieces of black paper and ten pieces of white paper were added. July 8, 11.00 A. M., no reaction to papers, experiment discontinued.

Experiment 2—July 8, 11.25 A. M. Two *Libinias* were put on a black background and two others on a white background; 11.40, twenty pieces of white and twenty pieces of black paper were added to each dish.

Black background

5.25 P. M. Larger individual had two white pieces on its back, smaller one had one white piece.

White background

12.20 P. M. The smaller individual bore four half white papers and three black; the larger one carried white paper.
5.25 P. M. Large one had no decorations; small one as at 12.20.

5.45 P. M. Water changed, both animals cleaned and all papers thrown away; animals interchanged from black to white backgrounds and vice versa; ten fresh strips each were put in of white and black papers.

Black background

8.30 P. M. Large one had two black papers on its back.

July 9

7.20 A. M. Large individual same as last night; small one had half a black paper on top of head.

10.30. Changed water

11.15. Large one same, small one had one white and one black paper on it.

1.25 P. M. Large one had added a white paper to its two black.

*White background**July 9*

7.20 A. M. Small animal had one piece of black on top of head.

8.30 A. M. Small one had one black and one white.

10.30. Changed water.

11.15. Small one has two white and one black.

1.25 P. M. Small one had two black and two white; large one nothing.

Experiment 3—July 9, 2.00 P. M. Two clean Libinias were placed on a black background and two on white; put ten pieces of black and ten pieces of white paper in each dish.

Black background

3.00 P. M. Smaller individual had one black paper on back.

White background

2.25. Larger individual had one black piece on head; small one nothing.

Black background

3.17. Both with one black paper.

4.45. Large one, nothing; small one had one black and one white paper.

7.50. Same. Put in fresh water and took all the papers off the small animal.

July 10

8.20 A. M. Small one has one black, large one nothing.

2.00 P. M. Large one, six black; small one, one black.

White background

4.45. Large one with two black and one white; small one, nothing.

7.50. Same. Fresh water added and all the papers removed from the large animal.

July 10

8.20 A. M. Small individual with two white and one black; large one nothing.

2.00 P. M. Large one, nothing; small one with four white and one black.

Experiment 4—July 10, 2.07 P. M. Four clean Libinias were placed on white and four on black background; ten white and ten black papers were added to each dish. Animals in each dish numbered 1, 2, 3, and 4.

Black background

3.45. 1, 2 and 3 nothing; 4 carried one white.

4.30-8.00. Same.

8.15. 1, 2 and 3, nothing; 4 had two white, one black.

White background

3.45. 1 and 2 nothing; 3 bore one white; 4 bore two black and one white.

4.30-8.00. Same.

8.15. 1 and 2, nothing; 3 bore two white; 4, two black.

Experiment 5—July 11, 8.30 A. M. Same conditions as last experiment, except that the four Libinias which had been on the black and white backgrounds respectively, were interchanged.

Black background

8.05 P. M. Nothing on any of the animals. Fresh water added.

White background

8.05 P. M. Nothing on any of the animals. Fresh water added.

Black background

July 12

6.45 A. M. Nothing on any.
 10.45. One black paper on
 one individual; the others,
 nothing.
 2.15. Same.

White background

July 12

6.45 A. M. Nothing on any
 of the animals.
 10.45 A. M.—2.15 P. M. Same.

Five other experiments of the same nature were performed and they are summarized in Table III. The results show little evidence of discrimination between white and black. There is a rather noticeable predominance of selections of black on a black background but this is due mostly to the selection of six black papers by one individual in Experiment 3. The matter seemed worthy of further investigation, however, and another set of experiments was carried out; these are described in the next section.

TABLE III

SHOWING THE RESULTS OF ALLOWING LIBINIAS TO DECORATE WITH BLACK AND WHITE PAPERS WHILE RESTING ON AN ENTIRELY BLACK OR WHITE BACKGROUND

Background	Black		White	
	Black	White	Black	White
Papers selected.				
Experiment 1.	0	0		
Experiment 2.	3	2	5	5
Experiment 3.	9	1	3	5
Experiment 4.	1	2	2	3
Experiment 5.	1	0	0	0
Experiment 6.	0	4	0	0
Experiment 7.	3	0	0	0
Experiment 8.	0	0	0	0
Experiment 9.	3	0	0	0
Experiment 10.	0	0	0	0
Total	20	9	10	13

(b) *Color Discrimination.*—The experiments to be described here were carried out in the same manner as those considered under black vs. white discrimination (p. 85), except that papers of four colors were put in the dishes, and six dishes were used instead of two, four of the dishes being covered with colored papers. The colors used corresponded with the following numbers

in Klingksieglk and Valette's color code: Red, 7; yellow, 201; green, 306; blue, 426. During each experiment six animals were placed in six dishes, having black, red, yellow, green, blue and white backgrounds respectively; each crab was given a choice of six colors of paper for decorating purposes, these were equally divided among sixty pieces. The series of experiments extended from July 18 until August 4. Table IV shows that there was again no evidence that *Libinia* has any ability to select colors which correspond to the background on which it rests.

From the experiments described it will be seen that *Libinia* showed no ability to discriminate colors. Professor S. O. Mast has carried out similar experiments and reached same conclusion. Furthermore, the late Millet Thompson of Clark

TABLE IV

SHOWING THE NUMBER OF COLORED PAPERS SELECTED BY *LIBINIA* ON VARIOUSLY COLORED BACKGROUNDS. B, BLACK; R, RED; Y, YELLOW; G, GREEN; U, BLUE; W, WHITE

Color of background.....	Black	Red	Yellow	Green	Blue	White
Experiment 1.....	0	1U	0	1U	2B, 1R, 1Y, 1W	0
Experiment 2.....	1R, 1B, 1W	4B, 1G	2Y, 2R, 3U	1Y	1U	2B, 2Y, 2G, 2R, 1W
Experiment 3.....	1U, 1W	1R, 2U	3R, 3Y, 3W, 2U	1Y, 1R	0	1Y, 1G, 2U, 2W
Experiment 4.....	1U	3R, 3U, 4Y	2R, 1W	0	2U, 1R 1G	1U
Experiment 5.....	0	0	1R, 1G, 1Y, 2U, 1W	1R, 1Y, 3 G	0	2B, 3G, 2Y, 2U, 2W
Experiment 6.....	1U	0	0	1R, 2Y, 2G	1U	2B, 1Y 1W
Experiment 7.....	1B, 4Y, 1G, 3U, 1W	1G	0	2Y, 1U, 1W	2G, 1W	3Y, 1U, 1R
Total.....	2B, 1R, 4Y, 1G, 5U, 3W	4B, 4R, 4Y, 2G, 5U	6Y, 8R, 1G, 7U, 5W	7Y, 3R, 5G, 2U, 1W	2B, 2R, 1Y, 2G, 3U, 2W	4B, 3R, 9Y, 6G, 6U, 7W

University, is said to have performed a series of experiments in which colored bits of hydroid and bryozoan colonies were used; he was unable to show that *Libinia* chose decorations similar to the environment.

The Larva of the Caddis Fly, *Neuronia postica* Walker.—The case of this larva is built of slender bits of leaves firmly bound together to form a brown cylindrical tube. This is a familiar object to one who collects from the brooks about Ann

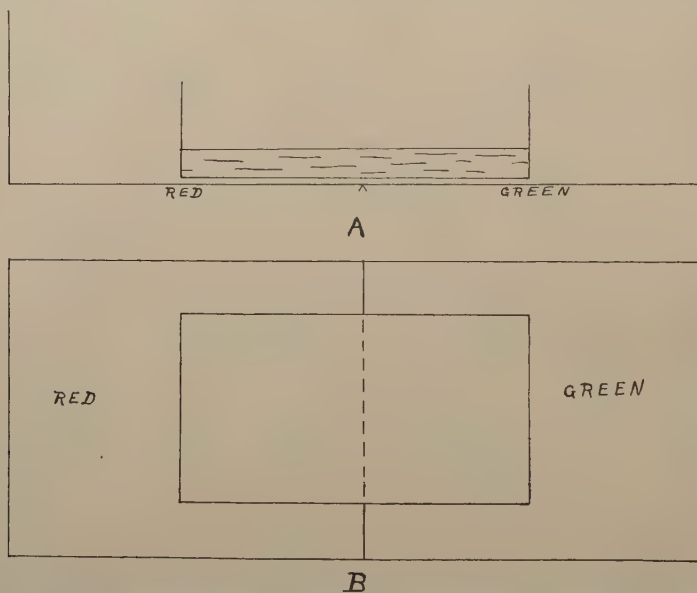


FIGURE 3—Plan of apparatus for testing the reactions of caddis fly larvae, A, section; B, ground plan.

Arbor, for the species is abundant. The dull brown of the case harmonizes well with the muddy plant covered bottoms; hence it is usually inconspicuous.

A series of experiments was performed to ascertain whether *Neuronia* larvae could be induced to select materials for the construction of their cases that would match color of the background on which they rested. The color boxes described in considering the reactions of the crayfish (p. 81, Fig. 1) were used.

On October 24, 1909, three larvae without cases were placed

in each of the six color boxes and left until November 5; on the latter date those in the green and yellow boxes were all found to be dead and only one was alive in each of the others (black, red, blue, white). On November 7, one fresh larva was put in both the green and yellow boxes; at the same time twenty-four strips of colored paper, measuring one by fifteen millimeters, were placed in each of the four other boxes; these papers were divided equally among the six colors used. On November 14, twenty-four papers were also added to the yellow and green boxes. On November 14, 20 and 28 all cases which had been built were removed and the larvae were given a new start with twenty-four fresh papers.

The colors of the papers from which these larvae made cases are shown in Table V. No evidence of selection of papers colored to match the background is indicated by the results.

Even though the larvae did not select papers for their tubes which matched the background, it seemed possible that the

TABLE V

RESULTS OF ALLOWING NEURONIA LARVAE TO BUILD CASES FROM COLORED PAPERS WHILE RESTING ON A MONOCHROME BACKGROUND.
W, WHITE; U, BLUE; G, GREEN; Y, YELLOW;
R, Red; B, BLACK

Color of background	Colors of papers composing cases			Total
	Nov. 14	Nov. 20	Nov. 28	
Black	1W, 2U, 2R	No case	Dead, no case	1W, 2U, 2R
Red	No case	3W, 3U, 2G, 1R, 2B	Dead, no case	3W, 2U, 2G 1R, 2B
Yellow		1W, 3U, 1G, 2Y, 2R, 2B	1W, 2U, 2B	2W, 5U, 1G, 2Y, 2R, 4B
Green		1W, 3U, 2Y, 1R, 1B	No case	1W, 3U, 2Y, 1R, 1B
Blue	2U, 3R, 1B	1W, 3U, 2R, 1B	3U, 2R, 1B	1W, 6U, 4R, 2B
White	1W, 2U, 1R, 1B	*	No tube	1W, 2U, 1R, 1B

*.Not in a definite tube but most of the papers in the box were fastened together.

prolonged sojourn in a monochrome environment might influence their locomotor reactions; an experiment was therefore conducted to test this point. On December 5, two cases bearing larvae which had been in red and green color boxes, seven and twenty-eight days respectively, were tested in the apparatus shown in Figure 3. A rectangular glass dish containing water was placed in a box painted half green and half red. They were placed separately in the center of the dish and allowed to move toward either end. The larva from the red color box went to the red end of the dish six times and to the green end four times; the one from green box gave three reactions toward the red and two toward the green. No striking tendency to go toward either color was shown.

From these experiments the conclusion may be drawn that the *Neuronia* larva selects the objects for its case without reference to their color. However, it will nevertheless generally be protectively colored.

The Spider, *Misumena aleatoria* (Hentz) Emerton *.—This crab-spider is common in the flowers of the fields about Ann Arbor and is readily collected with a beating net. Its particular interest for this paper lies in the fact that it has two striking color varieties, one white and one yellow, Emerton ('02) says: "Whether spiders prefer flowers like themselves is an unsettled question; at any rate, *Misumenas* of all colors and both sexes have been found on white flowers."

Naturally, the first question to be answered is whether there are more yellow *Misumenas* on yellow than on white flowers and vice versa. The results of collections made during the months of August and September in 1909 and 1910 are shown in Table VI.

Some of the spiders collected could not be classed as white or yellow and two other varieties were made to include this comparatively small number, i. e., green, for those with a greenish tint, and red, for those in which the abdomen was nearly covered with reddish brown blotches. The flowers from which collections were made were as follows; Yellow—golden rod (*Solidago* sp. ?) also a few from sunflowers (*Helianthus* sp. ?) and "butter and eggs"

* All the spiders used in these experiments were not accurately determined to belong to this species; all the adult females, however, agreed with Emerton's ('04) description of *M. aleatoria*; the smaller males are difficult to identify and some of them may have belonged to other species of the genus *Misumena*.

TABLE VI

SHOWING THE TOTAL NUMBER AND THE COLORS OF SPIDERS COLLECTED WITH A BEATING NET FROM WHITE AND YELLOW FLOWERS

Color of flower.	White				Yellow			
	White	Yellow	Green	Red	White	Yellow	Green	Red
Color of spiders.								
Number of spiders collected.	215	14	14	12	46	423	15	12
Per cent. of total number	84	6	6	4	9	85	3	3

(*Linaria vulgaris*); white—boneset (*Eupatorium perfoliatum*), domestic buckwheat (*Fagopyrum esculentum*), and a few from milfoil (*Achillea Millefolium*). Table VI shows clearly that a majority of white or yellow spiders are found on the correspondingly colored flowers.*

Having determined that *Misumenas* usually correspond in color to the flowers in which they lurk to capture their prey, attention was next directed to the causes determining this correspondence. In this connection three possible explanations were tested to some extent: (1) color changes, (2) positive reactions toward certain colors or flowers, (3) the elimination of individuals not matching their color backgrounds by predaceous enemies.

(a) *Color changes*. Efforts were made to induce *Misumenas* to change from white to yellow, or from yellow to white, by keeping them on white or yellow backgrounds.

Experiment 1. Spiders were placed in covered glass dishes surrounded on all sides but the top by colored paper. The colors were the same as those used in the experiments with *Libinia* (p. 89). On August 20, 1909, one white spider was

* Although collections were not very extensive from flowers other than yellow and white, the following results show that the majority of spiders were white.

Color of spider.	White	Yellow	Green	Red
<i>Epilobium angustifolium</i> —purple.	10	0	0	0
<i>Eupatorium purpureum</i> —purple.	30	3	1	0
<i>Polygonum</i> sp.?—pink.	1	0	1	0
<i>Aster laevis</i> —blue.	10	2	0	0
<i>Erigeron annuus</i> —yellow and white.	4	1	6	0
Total.	55	5	8	0
Per cent.	81	7	12	0

placed in each of the six dishes (black, red, yellow, green, blue and white respectively); on August 23 two more white spiders were added to each dish. Daily notes were then made as to the condition of the eighteen spiders under observation until September 6, a period of fourteen days (during which time eight individuals died). Although four individuals changed a little and looked as though they might be about to take on a slightly different tint, none of the animals assumed a color that could be called anything but white.

Experiment 2. September 3, 1909, five white spiders were placed on a bunch of goldenrod flowers (*Solidago* sp. ?), yellow, and five yellow spiders on a bunch of milfoil (*Achillea Millefolium*), white. The flowers were in bottles which rested in large pans of water so that the spiders could not escape. Both dishes were placed before a window so that they were illuminated by the morning sun. The spiders were observed daily until all had been drowned. On the milfoil three were drowned after one day, one after four days, and the last after fifteen days; on the yellow flowers, three lived four days, one eight, and one thirteen. None of these spiders showed any color changes.

Experiment 3. For this experiment two of the color boxes described on page 81 were used (Fig. 1). On August 31, 1909, seven yellow spiders were placed in a white box and a like number of the same color in a yellow box. All but one of these remained alive for more than seventeen days; none of them changed color.

On September 6, 1909, six white *Misumenas* were placed in a white box, and a corresponding number of the same color in a yellow box. These were all alive on September 17 (10 days); on September 24, only one was alive in the white box and three in the yellow; on October 7, there was no further mortality in the white box but all those in the yellow had died. None of these spiders changed color.

Experiment 4. Methods like Experiment 1. Up to November 27 the glass jars containing the spiders rested on a shelf in a laboratory room; after that they were on a table before a window.

September 19, 1910, six yellow males and two yellow females were put in two "white jars." Two of the males turned white between October 8 and 21, all the others died before that time except one male (who remained yellowish until he escaped on November 10). On November 24, the two surviving (then white)

males were placed in a yellow jar; on December 18, one died and the other was still white on December 31.

September 22, 1910. Twelve white males and four white females were placed in four yellow jars. None of these *Misumenas* changed color, though five of the males were alive December 22.

Experiment 5 was carried out in order to ascertain if light *per se* has any effect on the colors of *Misumena*. On September 13, 1910, eight spiders were placed in four glass jars. Two of these jars contained two yellow spiders each, and the other two contained the same number of white individuals. The jars were so placed that half the spiders of each color were in the dark, while the others were exposed to direct sunlight before a window. No change could be observed to have occurred in the colors of any of the spiders on September 24. On October 8, all the white spiders died, also one of the yellow individuals. Light or its absence induced no observable color change during twenty-two days.

From the five experiments described it is apparent that the few color changes which took place were too slow to be of much advantage to a spider in nature. Most of the *Misumenas* did not change color and those that did would hardly have had time to adapt themselves to a particular flower before it withered.

(b) *The Reactions of Misumena to flowers and colored backgrounds.* As a preliminary step the reactions of *Misumena* to white light were tested by means of a horizontal beam from a one-glowler Nernst lamp. During these experiments the lamp was placed at one end of a table and the spiders were allowed to run from a vial on to the table at a distance of forty centimeters from the source of light. Five reactions for each of five individuals were taken. None of the spiders moved directly toward or away from the light but in every case they went ahead in a rather erratic manner and climbed up, or ran along the edge of the black side screens which were used to cut off their view from objects in the room where the experiments were performed. From these results it was assumed that *Misumena's* reactions to directive light were negligible so far as their influence on the reaction experiments which followed were concerned. This conclusion was supported by the general behavior of spiders in the field and laboratory, no indications of marked reactions to light *per se* were ever noted.

Experiment 1. On August 21, 1909, twenty-four white and twenty-six yellow *Misumenas* were collected and placed together in a large rectangular glass dish forty centimeters long, twenty-five centimeters wide and twelve centimeters deep. Except for the cover, one-half of this dish was completely enclosed in yellow, the other half in white. The fifty individuals were examined two or more times a day until August 26.

There appeared to be no tendency for yellow or white individuals to come to rest more often on one color than on the other. There were always about as many white as yellow individuals in either end of the dish. This experiment then gave no evidence that *Misumena* seeks a background which matches its color.

Experiment 2. In this experiment spiders were placed in a vial and allowed to go from it through a small hole in the side of a box (measuring 7 cm. high, 15 cm. long, and 11 cm. wide). This box was lined half with yellow paper (c. c. 176) and half with white paper in such a way that it was divided vertically by the two colors at right angles to the long axis. The spider was admitted on the floor of the box and on the line of division between the white and yellow; its subsequent move-

TABLE VII

SHOWING THE DIRECTION OF MOVEMENT TAKEN BY SPIDERS IN A BOX COLORED HALF YELLOW AND HALF WHITE. "0" INDICATES NO MOVEMENT, OR THAT THE MOVEMENT COULD NOT BE SAID TO BE IN THE DIRECTION OF EITHER COLOR.

Color of spider.....	Yellow			White		
	Yellow	White	0	Yellow	White	0
Direction of movement...						
Number of reactions.....	46	49	5	10	11	4

ments were observed and recorded; after that it was removed and another individual was tested. The results of these tests are given in Table VII; they show no evidence of selection of color environment to correspond with the color of the spiders. In fact the different individuals appeared to wander off in any direction after entering the box.

The *Misumenas* used in the experiments just described were individuals which had been kept in the laboratory for a day or two and it was thought that animals freshly collected might show different results if tested at once in the field. Accordingly, the "yellow-white" box was carried out on several collecting

TABLE VIII

SHOWING THE DIRECTION OF MOVEMENT TAKEN BY NEWLY COLLECTED SPIDERS TESTED IN THE FIELD IN A BOX COLORED HALF WHITE AND HALF YELLOW. "0" INDICATES NO DEFINITE MOVEMENT WITH RESPECT TO EITHER COLOR.

Color of spider.....	Yellow			White		
	Yellow	White	0	Yellow	White	0
Direction of movement...						
Number of reactions.....	35	31	11	14	8	3

trips and the spiders were tested as they were taken from the net. The results of these tests are given in Table VIII. Again there is absolutely no evidence that *Misumena* shows a positive reaction toward a background colored like itself.

Experiment 3. This experiment was carried out on a table before an open window. *Misumenas* were allowed to crawl separately from a vial to the surface of the table at a point midway between two black screens; the vial was then removed. The screens were inclined at an angle of about 75 degrees to the surface of the table and a cluster of flowers was fastened to each in such a way that it was exactly 9.4 centimeters from the spider. The two flower clusters were as nearly the same size as possible; one was goldenrod (*Solidago* sp?) like that from which the yellow spiders had been collected, the other was milfoil (*Achillea Millefolium*) from which some of the white spiders had been secured. Each spider as it reached the surface of the table was, therefore, the same distance from a white and a yellow flower cluster. A total of fifty tests were recorded from five yellow *Misumenas*, ten from each individual. In four cases spiders went to the white flower, in five to the yellow flower; the other forty-one reactions were without apparent reference to the flowers. Several times spiders walked up one of the screens and passed within a centimeter of a flower without swerving.

Experiment 4. On September 15, 1910, thirty-two freshly collected spiders, sixteen yellow and sixteen white, were tested

in the field. An elongated space twenty-eight centimeters wide was cleared in the shadow of a tree trunk. On each side of this space at its middle a row (13 cm. high and 30 cm. long) of flowers was placed, the flowers on the right being yellow (*Solidago* sp?), those on the left, white (*Eupatorium perfoliatum*). The observer sat against the tree at one end of the cleared space, and therefore his movements did not cause the spiders to move toward one bunch of flowers or the other. The spiders were allowed to hang from a thread, and were then placed half way between the two rows of blossoms. Their reactions are summarized in Table IX; there is no evidence that the spiders went oftener toward flowers colored like themselves.

TABLE IX
REACTIONS OF YELLOW AND WHITE SPIDERS TO COLORED FLOWERS IN THE FIELD

Color of spider	Yellow		White		
	Yellow	White	Yellow	White	No movement toward flowers
Number of reactions	7	9	6	7	3

Experiment 5. The behavior of *Misumenas* placed on yellow and white flowers was observed with some care in the field. It was thought that white spiders might be less active on white than on yellow flowers, and that yellow spiders might show a similar response on yellow flowers; i. e. that there might be some evidence that yellow or white spiders were less restless when surrounded by a background colored like themselves.

On September 16 and 17, 1910, forty *Misumenas* were placed on goldenrod and buckwheat; half these were yellow and half white, and equal numbers of each color were placed on each kind of flower. Furthermore, every flower used was a part of a large field of the same kind. The behavior of each spider was carefully observed for two hours or until it had moved beyond the writer's field of observation. Both the days chosen for these experiments were clear with bright sunshine.

The behavior of the spiders varied greatly; some individuals at once hid themselves beneath a spray of the flower, others chose a conspicuous place in an exposed situation; some re-

mained almost where they were placed for a long time, others at once spread gauzy aeroplanes and ballooned away to new fields; no two spiders did similar things and it is impossible to tabulate the results. The writer quotes the following from his field note-book: "After two days I can see no difference in the way yellow spiders behave on white and yellow flowers; white spiders same." No difference that could be assigned to the influence of color environment was observed.

(c) *The Reactions toward bees and wasps.* In order to ascertain whether the behavior of *Misumena* toward colors was such that most individuals would escape in the presence of predaceous insect enemies, some observations bearing on this question were made.

On two occasions, two or three hours were spent in watching the behavior of *Misumenas* placed on flowers which were being frequently visited by bees and wasps. On September 14, 1910, three yellow individuals were placed on a bunch of fleabane daisies (*Erigeron annuus*), which was being prospected constantly by from fifty to seventy-five bees and wasps. The honey bee, *Apis mellifica*, was the most frequent visitor, and among the wasps, the commoner representatives were two species identified as *Polistes pallipes* and *Philanthus solivagus* by Mr. S. A. Rohwer, to whom they were referred by Dr. L. O. Howard. One of the *Misumenas* at once hid itself deep in a cluster of flowers and was not seen again during the two hours the observation lasted. One of the other spiders hung on the under side of a small flower cluster, and the third chose a position in plain sight on top of one of the highest sprigs of the fleabane. The individual which was hanging on the under side of the flowers avoided bees and wasps; once it moved away when a bee approached, but it usually remained perfectly motionless and concealed itself as much as possible when a winged disturber came near. On the other hand, the *Misumena* which chose the conspicuous situation behaved in quite a different manner; it rested with outstretched legs ready to attack; when one of the largest wasps (*Philanthus solivagus*) alighted near, it rushed toward the intruder with raised legs, and the wasp at once went elsewhere to forage.

On September 15, 1910, five yellow spiders were put on boneset blossoms and watched from 2.30 P. M. until 5.00 P. M. One dropped to the ground at once, one wandered a good deal from

one place to another, a third hid itself on the under side of a flower, the remaining two took positions on the tops of flowers in plain view and assumed a watchful attitude, apparently seeking prey. Neither of the two latter individuals seemed to be disturbed by the close proximity of bees and seldom changed their positions when approached.

As a result of these and other similar observations made in the course of different experiments the writer was convinced that the behavior of *Misumena* is not finely adapted to enable them to escape predaceous hymenopterous insects. The reactions of different individuals apparently depend upon their physiological state. Some (hungry ?) spiders are pugnacious and ready to attack almost anything that approaches, other are secretive and remain in hiding.

DISCUSSION OF EXPERIMENTS

For the sake of conciseness the relation of the writer's experiments to the literature concerning similar investigations has been reserved for discussion at this place. This plan has the additional advantage of bringing all the conclusions together before we pass to the "general considerations" following. The arthropods used for the foregoing experiments will be considered separately.

The crayfish.—Protective resemblance is common among crustaceans. Beebe ('09) points out a very striking case in the mangrove crabs on Trinidad Island, where a certain species shows a great variety of colors which correspond closely to the roots it frequents. Many crustaceans have been shown to undergo marked color changes which bring about a general correspondence with the colors in their environment, and careful studies have been made of these changes in certain Decapods and Mysidaceans by Keeble and Gamble ('00, '04), and in the crayfish by Kent ('01). More recently Franz ('10) has investigated the chromatophores of *Pandalus* and *Crago*. All of these investigators agree that the color of the background is an important factor in inducing color changes.

There is evidence that color changes in the skin may be influenced by stimuli acting through the eye and central nervous system (Frohlich, '10; Keeble and Gamble, '04), nevertheless,

color changes are without doubt commonly brought about by the direct effect of light on the chromatophores which contain pigment (Keeble and Gamble, '04). Rynberk ('06) in his excellent summary of the whole question says (p. 427) that such changes are not voluntary, and that they are induced not through seeing so much as by the changes brought about through nourishment.

The experiments described in the present paper make it apparent that the reactions of the crayfish are not influenced by a prolonged sojourn in a monochrome environment even though there is a corresponding change in the color of the skin; i. e. crayfishes show no tendency to go toward the color which most nearly resembles their own. Keeble and Gamble ('00) make a statement concerning another crustacean, *Hippolyte varians*, which apparently does not harmonize with this conclusion—they say (p. 601) “That the prawns exert powers of selection with respect to their weed, this will be readily realized from Pls. 32 and 33, figs. 1 to 9, representing prawns placed in a dish with sea water, to which subsequently pieces of different coloured weeds were added. The prawns were left free to select their weeds, and, as will be seen in the figures, they succeeded in making wonderfully accurate color matches.” Notwithstanding the striking similarities they present in their figures, Keeble and Gamble give no *evidence* to show that the prawns selected particular weeds on account of their *color*, and the selection may have been due, wholly or in part, to some other factor, such as food or a particular sort of tactile or chemical stimulation to which the prawns had been accustomed. The following quotations from Keeble and Gamble's paper support this view (p. 621): “Its prime object in life is to anchor itself. Once fixed, rather than release its hold it will allow the ebb tide to leave it stranded. By its immobility it has grown into its surroundings and become colored like them. Should it become separated from its favorite weed its movements become of an aimless sort.” *Hippolyte* evidently becomes accustomed to a certain seaweed; it seems but natural that if it were separated from this and placed in a dish containing various plants it would choose the one to which it had become accustomed; and furthermore, it seems to the writer that such selection could not be assumed to be due to color alone unless it were shown that the

prawns selected a particular color, without the presence of a particular weed. Until it has been proven that such is the case, we have not sufficient evidence, I believe, to permit the assertion that any crustacean selects an environment to suit its own color.

The caddis-fly larva.—Poulton ('90, p. 77) says: "The well known cases of caddice-worms (Trichoptera) are partly for concealment and partly for defense, they are built of, . . . any suitable objects which are abundant at that bottom of the stream in which they live." He uses the caddis-fly case as an example of "adventitious protection" where "animals cover themselves with objects which are prevalent in their surroundings and are of no interest to their enemies." The experiments described in this paper show that caddis-fly larvae do not select objects for their cases which will make their colors correspond with the general tint of the background. Nevertheless, they are protectively colored as a rule.

The spider-crab.—In 1907 Minkiewicz published an account of the reactions of spider-crabs; in which he stated that he had induced individuals of several genera (*Maja*, *Pisa*, *Inachus*, *Stenorynchus*) to select certain strips of paper, from a variety of colors, which corresponded to the background on which they rested. Furthermore, Minkiewicz maintained that crabs which had selected decorations of a certain color showed a positive chromotropism toward the same color when they were placed in a particolored dish. These results seemed remarkable for Bateson ('89) had previously performed similar experiments with three species from the same genera used by Minkiewicz and reached quite different conclusions. He says (p. 214): "There is certainly no disposition on the part of *Stenorynchus* dressed in any color, say green, to take up a position amongst green weed or indeed amongst weed at all, and so on, while some individuals which have taken up their station among weeds do not dress themselves at all." Poulton ('90) also, quoting Bateson, says: "*Stenorynchus* does not betray any disposition to remain in an environment which harmonizes with its dress."

The writer's experiments on *Libinia* support Bateson's conclusions. Before Minkiewicz's results are accepted the species

he studied ought to be re-examined by another investigator. The evidence as it now stands cannot be said to prove that decorator crabs choose colors for concealing themselves which harmonize with their surroundings.

The crab-spider.—Emerton ('02) says: "Whether spiders prefer flowers colored like themselves is an unsettled question; at any rate, *Misumenas* of all colors and both sexes have been found on white flowers." From the results set forth in the present paper there can be little doubt that the majority of *Misumenas* are to be found on flowers colored like themselves. Thayer ('09) figures *Misumenas* as an example of "obliterative coloration," and in experiments described in this paper it is shown that its colors usually harmonize with the background. The question is, whether the presence of a majority of yellow spiders on yellow flowers and of white spiders on white flowers, is due to color changes in the spider itself, or to the selection of a particular background by each individual, or to some other influence.

McCook ('89-'93, vol. 2, p. 341) says the color of spiders may be influenced by a variety of factors, among these moulting, advancing age, gestation, muscular contraction, sex difference and excitement may be mentioned as being sometimes important. Nevertheless he says (vol. 3, p. 51), that there are no authentic cases of rapid color changes in American spiders, and (vol. 2, p. 271) because the color changes of *Misumena* are so slow, he says, "we are therefore compelled to the conclusion . . . that the spider sought the flower and settled upon it, either accidentally or by choice." Beddard ('92, p. 111) mentions a rapid color change described by Heckel, in a spider which belongs to the same family as *Misumena*. This species was *Thomisus onustus*, which he says has three color varieties in the flowers of *Convolvulus amensis*, and two other colors in other flowers. These varieties correspond closely to the flowers and Heckel maintained that these spiders could change their colors in three or four days. Beddard says, however, that the evidence for color change was not by any means conclusive. Davenport ('03) mentions a light colored sand-spider which became gradually darker when placed on grass.

In the knowledge of the writer, the experiments described in the present paper are the first in which spiders have been allowed

to remain for a long period of time on a background which might induce color changes. Out of the sixty spiders used only two showed any color changes and in both these cases more than a month elapsed before the skin had turned from yellow to white. Furthermore, McCook ('89-'93, vol. 2, p. 325) demonstrated that spiders of a single species may show striking color variations in the same habitat. From these facts the conclusion is warranted, that *Misumena* does not change its colors rapidly nor with enough uniformity to make such changes of importance. This is apparently what McCook believed to be the case.

If, however, we maintain that the color changes of *Misumena* are unimportant in relation to protective coloration, we must examine other alternatives with all the more care. McCook says: "We are compelled to the conclusion" that *Misumena* "sought the flower and settled upon it, either accidentally or by choice." Despite his cautious statement in the sentence quoted, he evidently felt that spiders had some power of color discrimination, for he states (vol. 2, p. 367), without unfavorable comment, that Mrs. Treat found that *Misumena* would not stay on a background of a different color from its own, and he also says (p. 335) that the male spider is conscious of the colors of the female. The Peckhams ('87a) had previously shown that spiders showed a preference for certain colors when they were allowed to choose from several on which they might rest, and they state distinctly ('95, p. 261): "We, ourselves, are of the opinion that all the experiments taken together strongly indicate that spiders have the power of distinguishing colors." They also affirm that certain attids can see small objects distinctly at a distance of at least twelve inches.

In the light of these observations it might reasonably be expected that *Misumena* would show a tendency to seek an environment colored like itself, but this was not the case, in the writer's experiments. When yellow and white spiders were given an opportunity to choose between white and yellow papers or flowers they did not do so either in the laboratory or in the field; nor was any difference in the degree of activity on flowers of either color manifest. We are, therefore, forced to conclude that *Misumena* neither changes color rapidly to match its surroundings, nor seeks an environment colored like itself.

It is therefore not within the province of this investigation

to attempt to discover just what factors are responsible for a preponderance of yellow *Misumenas* on yellow flowers and of white individuals on white flowers. The writer has some evidence that such distribution may be due to the attacks of predaceous enemies, but it is not conclusive, and he rests his case here without attempting to discuss this or other factors. Whatever the cause of the general correspondence between *Misumena* and the colors in its environment, it is not due to color change nor positive chromotropism.

GENERAL CONSIDERATIONS

Coloration of Arthropods. Arthropods are sharply separated from all other groups of invertebrate animals; nevertheless, they possess certain common structural similarities which indicate a genetic relationship among the members of the different classes. There is great diversity among the different groups of arthropods, not only in structure but also in habits, and, if we compare the four chief classes, coloration is not by any means the least variable feature.

The colors of crustacea depend primarily upon chromatophore systems (Keeble and Gamble, '00, '04; Frohlich, '10; Franz, '10). These are usually deep seated and there is a migration of pigment granules in them to bring about more or less striking color changes which make the animals resemble their environment with varying degrees of accuracy (Beebe, '09; Keeble and Gamble, '00; Kent, '01). In many crustaceans the color phases are strongly periodic, appearing alternately with day and night, (Keeble and Gamble, '00), but the color changes are, nevertheless, chiefly induced by the presence or absence of light together with the tint of the background (Keeble and Gamble, '00; Kent, '01; Frohlich, '10; Franz, '10). The color changes of some crustaceans are apparently controlled in part by the nervous system, but there is no doubt that, even in such cases, changes may be brought about by the direct effect of light on the chromophores (Keeble and Gamble, '00; Frohlich, '10).

The colors of Myriapods have not been studied, to the knowledge of the writer, and they are comparatively uninteresting, for the color of many species appears to be mostly in the chitinous exoskeletal covering.

Spiders, the most common arachnids, present a great diversity

of colors and color patterns. No indubitable cases of rapid color changes have been reported, and McCook, one of the foremost students of spiders, points out ('89-'93, vol. 2, p. 325) that a single species may show a number of striking color varieties in the same habitat; the coloration is apparently not accurately adjusted to a particular background.

The insects show striking adaptation to aerial life, and also to a great diversity of habitats. Numerous colors and color patterns have been developed along rather definite lines (Mayer, '97; Tower, '03). A host of insects show protective resemblance and a few have been observed to undergo slow changes which make them more nearly resemble their surroundings (Poulton, '88; Davenport, '03). Kellogg ('05) in his work on American insects says (p. 600) the colors of insects are "fixed by the time they reach the adult stage," but a striking diurnal color change has recently (Schleip, '10) been demonstrated in *Dixippus morosus*. In this case there is a diurnal migration of pigment granules in a single layer of syncytial hypodermal cells. The chief factor which brings about this migration is the presence or absence of light, but the changes have a strongly developed diurnal periodicity and continue for as much as seventy-eight days in the dark.

Color discrimination.*—Bateson ('89) and Merejowski ('81) maintained that there is no color discrimination* manifested by the reactions of crustacea but Minkiewicz ('07) takes an opposite view. On account of the results of the experiments described in this paper (p. 88) the writer is disposed to agree with the results of the earlier investigators. The Peckhams ('87, '87a) firmly believe that spiders can discriminate colors, and Lubbock ('79), Lovell ('10) and Turner ('10) are of the same opinion in regard to hymenopterous insects. However, the whole question of color discrimination will bear further investigation. The present evidence is fragmentary, and some of it by no means conclusive.

Protective coloration.—Di Cesnola ('04) has demonstrated that protective coloration may preserve an insect from the attacks of its enemies, and there is little reason to doubt that protective

* Color "discrimination" is not intended to assume that arthropods see color as we see it, but only that they may be able to recognize a difference between colors or intensities of color.

resemblance is of value to most arthropods. However, Keeble and Gamble, ('04, p. 363) conclude from their exhaustive study of the coloration and color changes of crustaceans, that "The phenomena presented by these pigments are not exhaustively explained by any 'protective hypothesis,' " and Beddard ('92) maintains that color is not a protection against invertebrate foes. Although protective coloration is generally efficacious in preserving arthropods from the attacks of enemies it is not always perfectly adapted to its purpose (p. 99) and is often only effective for one particular enemy.

Reactions in relation to color environment.—In the present paper it has been shown that none of the four animals tested, though protectively colored, show any tendency to seek the background that harmonizes with their own coloration. In fact, the writer knows of no published observation which proves that any arthropod does this. Minkiewicz ('07) maintains that *Maja* and other decorating crabs select colors for their backs which correspond with the tone of their surroundings, but Bateson's ('89) experiments on the same kinds of crabs and the experiments with *Libinia* described in this paper make his results seem doubtful; Keeble and Gamble ('00) believe that in their experiments *Hippolyte* selected the background which most nearly matched its own color, but they give no evidence to show that the prawns did not select a certain sea weed on account of some quality other than color. Such a careful observer as McCook ('89-'93, vol. 2, p. 335) concludes that spiders which conceal their nests with foreign objects do so without recognizing their protective value. In this connection it is interesting to note that Marshall and Poulton ('02, p. 323) say: "Insectivorous invertebrates are not capable of appreciating warning colors, but have to taste all their captures." Nevertheless, they believe (p. 424) that butterflies select a general habitat where they are well protected.

Among the insects perhaps the best illustration of protective behavior coupled with absolute disregard for color environment is exhibited by the walking-sticks. Both Stockard ('08) and Schleich ('10) have shown that the behavior of these animals is suited in the highest degree to protect them *except* for the fact that they do not rest upon colors in their habitat which match

their own. A walking-stick will maintain a difficult attitude for a long time rather than disclose its presence by the slightest movement, thus indicating by its reactions that it has some recognition (not necessarily recognition on the part of the individual, but recognition at least so far as the race is concerned) that it is protected, but it takes no cognizance of color. Furthermore, Schleip ('10) has shown that the color changes of the walking-stick have no relation to the color of the environment, but are induced chiefly by light.

Adaptation.—Thayer ('09) would have us believe that all animal coloration is protective (concealing); not necessarily at every moment of an animal's life, perhaps only at some infrequent moment of great need. His arguments are very convincing and many of his conclusions seem quite probable. If the *Misumenas* described in this paper are used as an illustration, we can readily imagine that the presence of two color varieties which resemble the commonest flowers might be a valuable asset in the struggle for existence. Yellow or white flowers grow together in great fields and a spider would often find a suitable color background if it were in the proper habitat. It is possible that more yellow spiders are hatched year after year in large patches of goldenrod, and that white spiders are correspondingly more abundant where boneset abounds, but we can only surmise this, for nothing is known of the heredity of color in spiders, nor how much they wander from field to field. At any rate, if natural selection, having only two choices, picked out yellow and white to match the greatest number of flowers, it could not have chosen two colors that would be better for the locations where *Misumena* abounds.

We have many striking instances of extremely refined protective resemblances among the arthropods; examples like *Kallima*, *Misumena* and the walking-stick are familiar to every naturalist. Beddard ('92) mentions a spider which was so like a mass of bird excreta that it deceived the eye of a trained observer. Beebe ('09) in speaking of the mangrove crab says, "he grew to resemble his home root," and dwells at some length on the variety of mangrove roots and the accuracy with which the crabs imitate the patterns they present. Examples of this kind might be multiplied.

In speaking of insects, Kellogg ('05, p. 613) says, "natural

selection has undoubtedly been the chief factor" in producing protective resemblances, and, though there are some cases apparently not readily explained in this way (e. g. the bright colors of some deep sea crustacea, etc.), this statement seems to be generally applicable to arthropods as a whole. Furthermore, Packard ('04) believes that the patterns and color markings of arthropods have arisen through the operation of physical rather than biological factors. The evidence from the experiments described in this paper supports this view, for none of the animals appears to be able to take advantage of the colors in its environment in efforts to conceal itself.

The coloration of arthropods shows various degrees of adaptation to the factors in the environment. In one animal a certain factor may be of chief importance in causing color changes and in another animal the same factor may have little influence. For example, the color of the background is most potent in changing the colors of the crustacean, *Hippolyte varians* (Keeble and Gamble, '00), but has no effect on those of the insect *Dixippus morosus* (Schleip, '10).

CONCLUSION

From the foregoing experiments and discussion the writer believes that it cannot at present be affirmed that any protectively colored arthropod reacts toward colored objects or backgrounds in such a way that it can be said to have even an instinctive knowledge that it is protectively colored; i. e. arthropods do not *choose* the most favorable color environment on account of *color*.

BIBLIOGRAPHY

- BATESON, W. Notes on the Senses and Habits of Some Crustacea. *Jour. Marine Biol.*, Plymouth, N. S., vol. 1, pp. 211-214.
 1889.
 BEDDARD, F. E. Animal Coloration. *London*, viii + 288 pp.
 1892.
 BEEBE, C. W. AND M. B. A Naturalist in the Tropics. *Harper's Mag.*, vol. 118, pp. 590-600.
 1909.
 DAVENPORT, C. B. The Animal Ecology of the Cold Spring Sand Spit, with Remarks on the Theory of Adaptation. *Univ. of Chicago Decen. Publ.*, S. 1, vol. 10, pp. 157-176.
 1903.
 DI CESNOLA, A. P. Preliminary Note on the Protective Value of Color in *Mantis religiosa*. *Biometrika*, vol. 3, pp. 58-59.
 1904.
 EMERTON, J. H. The Common Spiders of the United States. *Boston and London*.
 1902. xviii + 225 pp.
 FRANZ, V. Zur Struktur der Chromatophoren bei Crustaceen. *Biol. Centralb.*,
 1910. bd. 33, pp. 424-430.
 FROHLICH, A. Farbwechselreaktionen bei *Palaemon*. *Arch. Entw.-Mech.*, bd. 29,
 1910. pp. 432-438, Taf. 13.

- KEEBLE, F. W. AND GAMBLE, F. W. *Hippolyte varians*. a Study in Color-change. 1900. *Q. Jour. Micr. Sci.*, vol. 43, pp. 589-698, pls. 32-36.
1904. The Colour Physiology of Higher Crustacea. *Phil. Trans.* London. S. B., vol. 196, pp. 295-388, pls. 18-23.
- KELLOGG, V. L. American Insects. *New York*. ix+674 pp. 1905.
- KENT, W. J. The Colors of the Crayfish. *Amer. Nat.* vol. 35, pp. 933-936. 1901.
- KLINGKSIEGK, P., ET VALETTE, T. 1908. Code des couleurs. *Paris*. 86 pp.
- LOVELL, J. H. The Color Sense of the Honey Bee. Can Bees Distinguish Colors? 1910. *Amer. Nat.*, vol. 44, pp. 673-692.
- LUBBOCK, J. Observations on Ants, Bees and Wasps. Pt. 5, Ants. *Jour. Linn. Soc.*, vol. 14, pp. 265-290. 1879.
- MCCOOK, H. C. American Spiders and Their Spinning Work. *Philadelphia*. 3 vols. 1889-1893.
- MARSHALL, G. A. K., AND POULTON, E. B. Five Years' Observations and Experiments (1896-1901) on the Bionomics of South African Insects, chiefly directed to the Investigation of Mimicry and Warning Colors. *Trans. Entomol. Soc.* London, 1902, pp. 287-541, pls. 9-23.
- MAYER, A. G. On the Color and Color-Patterns of Moths and Butterflies. *Proc. Boston Soc. Nat. Hist.*, vol. 27, pp. 243-330, pls. 1-10. 1897.
- MEREJOWSKY, C. Les crustacés inférieurs distinguent-ils les couleurs? *C. r. Acad. Sci.* Paris, T. 93, p. 1160. 1881.
- MINKIEWICZ, R. Analyse expérimentale de l'instinct de déguisement chez les Brachyures oxyrhynques. *Arch. Zool. Exper.* (1907), T. 7, notes e. rev., pp. xxvii-Lxvii.
- NEWBIGIN, M. I. Color in Nature. *London*, xii+344 pp. 1898.
- PACKARD, A. S. The Origin of the Markings of Organisms (Poecilogenesis) due to Physical rather than Biological Environment. *Proc. Amer. Phil. Soc.*, vol. 43, pp. 393-450. 1904.
- PECKHAM, G. W. AND E. G. Some Observations on the Special Senses of Wasps. 1897. *Proc. Nat. Hist. Soc. Wisconsin*, vol. 1, pp. 91-132.
- 1897a. Some Observations on the Mental Powers of Spiders. *Jour. Morphol.*, vol. 1, pp. 383-419.
1895. Sense of Sight in Spiders. *Trans. Wisconsin Acad. Sci.*, vol. 10, pp. 231-261.
1898. On the Instincts and Habits of the Solitary Wasps. *Wis. Geol. and Nat. Hist. Surv. Bull.* No. 2, 245 pp., 14 pls.
- PETRUNKOVITCH, A. The Sense of Sight in Spiders. *Jour. Exper. Zool.*, vol. 5; pp. 275-310, pls. 1-6. 1907.
- POULTON, E. B. An Enquiry into the Cause and Extent of a Certain Colour-relation between certain Exposed Lepidopterous Pupae and the Surfaces which immediately surround them. *Philosoph. Trans. Roy. Soc.* London vol. 178B, pp. 311-441, pl. 26. 1888.
1890. The Colours of Animals. *London*, xvi+360 pp.
- RYNBERK, G. VAN. Ueber den durch Chromatophoren bedingten Farbenwechsel der Tiere. *Ergebn. Physiol.*, bd. 5, pp. 347-571. 1906.
- SCHLEIP, W. Der Farbenwechsel von *Dixippus morosus* (Phasmidae). *Zool. Jahrb.*, bd. 30, pp. 45-133, Taf. 1-3. 1910.
- STOCKARD, C. R. Habits, Reactions and Mating Instincts of the "Walking Stick," *Aplopus mayeri*. *Extr. Pub.* 103, Carnegie Inst. Wash., pp. 43-59, pls. 1-3. 1908.
- THAYER, G. H. Concealing-Coloration in the Animal Kingdom. *New York*, xx+260 pp. 1909.
- TOWER, W. L. Colors and Color-patterns of Coleoptera. *Decen. Publ. Univ. Chicago*, vol. 10, pp. 33-70, pls. 1-3. 1903.
- TURNER, C. H. Experiments on the Color-Vision of the Honey Bee. *Biol. Bull.*, vol. 19, pp. 257-279. 1910.
- WALLACE, A. R. Darwinism. *London*, xx+494 pp. 1905.

THE RELATION OF STRENGTH OF STIMULUS TO RATE OF LEARNING IN THE CHICK

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From the Harvard Psychological Laboratory

ONE FIGURE

The experiments described in this paper were undertaken in order to learn under what strength of stimulus chicks most rapidly learn to make, respectively, an easy, a medium, and a difficult discrimination. Yerkes and Dodson discovered, in the case of the dancing mouse, that when "discrimination is extremely difficult the rapidity of learning at first rapidly increases as the strength of the stimulus is increased from the threshold, but, beyond an intensity of stimulation which is soon reached, it begins to decrease," while when "discrimination is easy, the rapidity of learning increases as the strength of the electrical stimulus is increased from the threshold of stimulation to the point of harmful intensity."¹ In other words, there appears to be an optimal strength of stimulus for each degree of difficulty of discrimination and the intensity of this optimal stimulus is less the more difficult the discrimination which is to be made.

It was proposed, then, to test the chick's rate of learning to discriminate by a method similar to that which had been employed with the dancing mouse. The work was done in the Harvard Psychological Laboratory and my thanks are due to Professor R. M. Yerkes for the plan of the investigation. The method of measuring the units of electrical stimulation and of calibrating the inductorium for that purpose is that of Doctor E. G. Martin of the Harvard Medical School.² The values of stimuli are relative, not absolute. Since the publication of the paper of Yerkes and Dodson, referred to above, Doctor Martin has discovered that certain corrections should be made which were not made for the original calibration published in the Yerkes and Dodson paper. All of the values of stimuli used in

¹ Yerkes, Robert M. and Dodson, John D. The relation of strength of stimulus to rapidity of habit formation. *Jour. of Comp. Neur. and Psych.*, 1908, vol. 18, pp. 459-482.

² Martin, E. G. A quantitative study of faradic stimulation. I. The variable factors involved. *Amer. Jour. of Physiol.*, vol. 22, pp. 61-74. II. The calibration of the inductorium for break shocks. *Ibid.*, pp. 116-132.

their investigation, as given in their paper, are relative as are those of the present paper.

The chicks. In the experiments sixty-eight barred Plymouth Rock chicks were used, six in preliminary tests and sixty-two under the established conditions of the experiments. The eggs from which the chicks were hatched were all obtained from a single poultry breeder and were guaranteed to be of pure stock. It was necessary, however, to purchase six young chicks of another breeder, but these also were warranted to be pure barred Plymouth Rock chicks and they were kept until it was certain that they presented no marks of difference from the rest of our chicks. Six chicks were used in every series of tests except three. Under the medium condition of discrimination with the weakest stimulus which was employed four chicks were used, while in each of two other groups a chick became sick during the progress of the experiments.

When the chicks were eight days old they were given two days of preliminary training (twenty trials) in order that they might learn the way through the experiment box. This was followed by twenty trials in order to ascertain whether the chick had a preference for either the lighter or the darker screen, thus *the training series began in every case on the twelfth day after hatching*. The training continued until the chick *had made twenty consecutive choices of the darker screen*. Thus the order of tests, for each chick, was (1) preliminary series, (2) preference series, (3) training series.

Apparatus. Figure 1 represents in its essential details the apparatus which was used in the investigation. The electrical connections are omitted and the electric key, K, was somewhat further to the right than appears in the figure. For convenience of description we may consider the apparatus as composed of three divisions or boxes. (1) The hover box, O; (2) the illumination box which contains the electric lamps and has for its nearer end the two opal glass screens N_2 and N_3 , and their frame or holder; (3) the experiment box which has the screens and holder for its remote end and consists of two compartments, A and C.

The hover box, O, had dimensions of 100 x 27.5 x 21 cm.³ Its floor was covered with sand and midway of its length was

³ All dimensions are given in the order length, width, and depth, and are inside measurements.

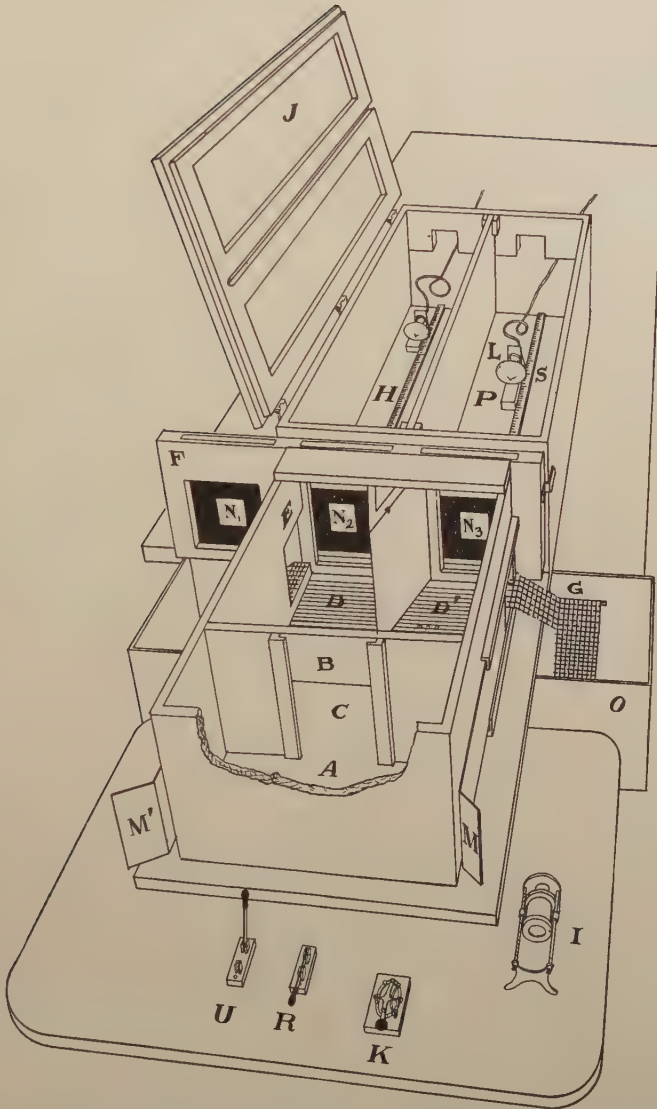


FIGURE 1—The figure is symmetrical, hence the letters G, E, L, and S must be understood to designate both the parts which they respectively mark and also duplicates of these parts on the opposite side of the figure.

1. *Hover box*: O, hover box; G, inclined planes (which were replaced by wooden platforms) of mesh wire leading from the doors, E, of the experiment box to the hover box.

2. *Illumination box*: H, left compartment; P, right compartment; L, lamps; S, metric scales.

3. *Experiment box*: A, compartment in which chick was placed; C, compartment in which it made choice of screens; B, gateway between A and C. D and D', electric passageways; N₂ and N₃, illuminated glass screens to be discriminated; E, openings to platforms at the sides of the experiment box; M and M', cardboard shutters for closing these openings; U and R, electric keys for extinguishing lamps in H and P, respectively; K, stimulus key; I, inductorium.

an electric, 16 c.p., lamp (not shown in the figure) in a small box fitted with milk-glass windows. This lamp afforded light and warmth to the young chick during the intervals when it was in the hover box, and gave to a small area in the middle of this box approximately the temperature of the brooder in which the chicks were reared. The result of this was that chicks placed in O hovered near this lamp and thus rarely made, at either end of the box, any sounds which might influence the chick in the experiment box in its choice of a passageway back to O.

The inclined planes, G, of box O were replaced, early in the experiment, by two small platforms at the level of the floor of the experiment box. From these platforms the chicks hopped down directly to the floor of box O. This change was made because it was found that while chicks very readily walk up an inclined plane it is very difficult and apparently unnatural for them to walk down such planes. This difficulty becomes evident if one tries to imagine a man descending a steep incline with his body leaning far forward. The inclined planes, therefore, to the inconvenience of the experimenter, served rather to toll the chicks in box O upward toward the small doors of the experiment box than to give a means of descent for the chick which was escaping from the latter box. The platforms obviated this difficulty.

The illumination box, 107.8 x 40.2 x 23.2 cm., was divided lengthwise into two compartments by a light tight partition. The inside dimensions of each compartment were 107.8 x 19.3 x 23.2 cm. Each of these compartments held an incandescent lamp of the oval reflector type with frosted globe. These lamps were mounted on slides so that they could be moved easily along the millimeter scales, S. They were rated as of 50 c.p. When photometered at the close of the experiments the lamp in the right compartment had an intensity of 42.6 c.p., the one at the left 41.2 c.p. By moving the lamps along their millimeter scales they could be changed in position from 8.5 cm. to 103 cm. behind the opal glass screens, N₂ and N₃, so that a wide range of intensities of illumination was available.

As already stated, three different conditions of discrimination were used. For the condition termed "easy" one screen was illuminated by a lamp 33.5 cm. distant, the other screen was not illuminated. For "medium" discrimination one lamp was

at 23.5 cm., the other at 98.5 cm., and for difficult discrimination the lamps were placed respectively at 23.5 cm. and 53.5 cm. from the screens.

The experiment box was, as shown in the figure, somewhat narrower than the illumination box. It was divided into two compartments, A, 30 x 16.7 x 21.3 cm., and C, 46 (from partition B to the glass screens N_2 and N_3), x 30 x 21.3 cm. A damp pad of felt was placed on the floor of compartment A during the experiments and a similar pad in compartment C extended from the partition, B, to within 2 cm. of the electric wires. These pads were used to moisten the feet of the chicks, for when dry the horny epidermis served to protect the animals perfectly from the electric stimulus. The opening, shown in the partition, B, between the two compartments was closed by a mesh wire door which could be opened by lifting it vertically. That half of the floor of compartment C which was nearest the screens was wound with seventeen turns of phosphor bronze wire of No. 20 A.S. gauge. The distance between the successive wires was 1 cm. This wire was in circuit with the secondary coil of the inductorium, I, and the circuit could be closed by means of the electric key, K. A V-shaped partition divided the wired portion of this compartment into two passageways, D and D'. From these passageways two openings (of which one, marked E, is shown) gave means of egress for the chick to the platforms (see p. 113) and thence to the hover box, O. They were closed by the cardboard shutters M and M'.

The two opal flashed glass screens, N_2 and N_3 , (N_1 was not used in the experiments) were each 12 cm. square. As already stated, the lamps were placed at different distances behind the two screens so that the latter differed from each other in brightness. Their relative brightnesses when photometered were roughly as follows:

For "easy" discrimination.....	0 ⁴ : 8.9 .
For medium discrimination.....	1: 13.7 .
For difficult discrimination.....	1: 5.1 .

While one screen was not illuminated under the condition of easy discrimination it had a surface of rather high reflecting power and, since the experiments were made in diffused day-

⁴ This screen was not illuminated. The zero is meant to indicate nothing more than that fact.

light, its value as perceived by the human eye was not darkness. This factor of reflected light was present throughout the experiments and made the difference in brightness of the two screens, as judged by the experimenter, much less than that indicated by the above ratio. Subjectively estimated the brightnesses of the two screens would stand, respectively, in the ratios 1 : 20 for easy discrimination, 1 : 4 for medium, and 1 : 2 for difficult.

A current of 2.1 amperes was supplied to the primary coil of the inductorium. The interruptions were 44 ± 5 per second. The positions of the secondary coil and the corresponding number of units of stimulation appear in table 1.⁵

Position of secondary	TABLE I	Units of stimulation
6	220
5	350
4	480
3	590

Method of the experiments. As a result of the experiments with the first group of chicks, Nos. 1-6 inclusive, it was found necessary to give all subsequent groups twenty trials in the experiment box in order that they might learn both ways of escape from it. The chick was first placed in compartment A of this box. The door in the partition was opened and it passed into compartment C. By drawing back the cardboard shutter M' the small door, E, was opened through which the chick escaped to the hover box. In the next trial it escaped at the right and so on until the preliminary series had been completed.

There was no difference of brightness between the two screens during the preliminary tests. During the first five of such tests under the condition of easy discrimination there was no light behind either screen, during the second five trials both lamps were at 33.5 cm. and so on. During the first five tests of medium discrimination both lamps were at 98.5 cm., during the second five at 23.5 cm., and the distances 53.5 cm. and 23.5 cm. were similarly used in the preliminary tests of the difficult discrimination.

⁵ For the calibration of the inductorium used in these experiments see the paper by Yerkes and Dodson, p. 467.

The experiments with the first group indicated also that chicks without preliminary training showed a very marked tendency to choose the more brightly illuminated screen. I therefore trained the chicks to escape to the hover box by choosing the *darker* screen. This was done also in order to make the results of my experiments more nearly comparable with those of Yerkes and Dodson, who trained their mice to select the

TABLE II

POSITIONS OF DARKER SCREEN FOR TWO PREFERENCE SERIES AND TWENTY-FIVE TRAINING SERIES

Subject..... Date..... Experiment.....

Series	Tests										R	W	Remarks
	1	2	3	4	5	6	7	8	9	10			
A	l	r	l	r	l	r	l	r	l	r			
B	r	l	r	l	r	l	r	l	r	l			
1	r	l	r	l	r	l	r	l	r	l			
2	l	l	r	r	l	r	l	l	r	r			
3	r	r	l	r	l	l	r	l	r	l			
4	l	l	l	r	r	r	l	r	r	l			
5	r	l	r	l	r	l	r	l	r	l			
6	l	l	r	l	r	r	l	r	l	r			
7	r	l	l	l	r	r	l	l	r	l			
8	r	r	l	l	r	l	r	l	r	l			
9	r	r	r	l	l	l	r	l	r	l			
10	l	l	l	l	r	r	r	r	l	r			
11	r	l	r	r	r	l	l	l	r	l			
12	r	l	r	l	r	l	l	l	r	l			
13	r	l	r	l	l	l	r	r	r	l			
14	l	l	l	l	r	r	r	r	l	r			
15	r	l	r	r	r	l	l	l	r	l			
16	l	r	l	l	l	r	r	r	l	r			
17	r	r	r	r	l	l	l	l	r	l			
18	l	r	l	r	r	l	l	r	l	r			
19	r	l	r	l	r	l	r	l	r	l			
20	l	l	l	r	l	r	l	r	r	r			
21	r	l	l	r	r	l	l	r	r	l			
22	l	l	r	r	l	l	r	r	l	r			
23	r	l	l	l	l	r	r	r	r	l			
24	l	r	l	l	l	r	r	r	l	r			
25	r	r	r	r	l	l	l	l	r	l			

white box, since, in the preference tests, the dancers selected the black one in more than one-half the trials.⁶

As described above (p. 112), the preliminary series were followed by two series of ten trials each, called "preference series," and designated in Table II by the letters A and B. On the day following the completion of the "preference series," the training series was begun and they were continued until the chick had made twenty consecutive choices of the darker screen. The order of change of illumination of the two screens appears in table II. The letter l indicates that the screen at the left was the darker one, the letter r, that the one at the right was the darker.

Since the preference series were preceded by the twenty preliminary trials, in which the chick escaped from the experiment box by going alternately through the right and left passages, the preference, so-called, was interfered with by the partially formed habit. Untrained chicks chose the brighter screen uniformly.

During the training series, if a chick chose the lighter passage-way, it received an electric shock, whereupon it usually retreated from the wires, the door of the darker passageway was opened and through that it escaped to the hover box. Under this stimulus the chicks quickly learned to choose the darker screen under conditions of easy and medium discrimination. A few chicks were unable, even after many trials, to learn to choose the darker screen under the difficult condition of discrimination.

Results of the Experiments. The results of the experiments appear in table III. This table gives the three conditions of discrimination, easy, medium, and difficult, the relative strengths of the stimuli, the numbers by which the individual chicks were designated, and, opposite each of these, the number of trials *which preceded twenty consecutive correct choices*, or the number of trials "up to the point at which errors ceased."

In order to spare the reader an annoying repetition of the phrases, "easy, medium, and difficult conditions of discrimination," I shall sometimes refer to them, respectively, as great, medium, and slight differences of illumination or brightness of the two glass screens.

It is evident from table III that under the condition of easy discrimination the rate of learning is more rapid the stronger

⁶ Yerkes and Dodson, loc. cit., p. 462.

TABLE III
GENERAL RESULTS OF EXPERIMENTS

Units of stimulation	Condition of discrimination		
	Easy Lamps at 33.5 cm. and darkness	Medium Lamps at 23.5 cm. and 98.5 cm	Difficult Lamps at 23.5 cm and 53.5 cm.
220 [*] Secondary at 6		No. 61s- 90 trials " 62s- 90 " " 65i-150 " " 66s- 90 " Av. 105	
350 Secondary at 5	No. 7-50 trials " 8-30 " " 9-20 " " 11-60 " " 12-60 " Av. 44	No. 25-50 trials " 26-80 " " 27-80 " " 28-40 " " 29-50 " Av. 60	No. 43-230 trials " 44-180 " " 45-110 " " 46-230 " " 47-180 " " 48-100 " Av. 171.6
480 Secondary at 4	No. 13-20 trials " 14-20 " " 15-30 " " 16-20 " " 17-20 " " 18-20 " Av. 21.66	No. 31-30 trials " 32-50 " " 33-30 " " 34-50 " " 35-50 " " 36-30 " Av. 40	No. 37-120 trials " 38-140 " " 39- 90 " " 40-220 " " 41- 80 " " 42-Failed. Av. 130
590 Secondary at 3	No. 19-20 trials " 20-10 " " 21-10 " " 22-20 " " 23-10 " " 24-30 " Av. 16.66	No. 49-70 trials " 50-80 " " 51-40 " " 52-30 " " 53-50 " " 54-30 " Av. 50	No. 55-Died. " 56-Failed. " 57-70 trials " 58-50 " " 59-40 " " 60-Failed. Av. 53.33
590 Secondary at 3		No. 67s-40 trials " 68s-50 " " 69s-30 " " 70i-80 " " 71i-20 " " 72i-60 " Av. 46.66	} Av. 40 } Av. 53.33

the stimulus. With a stimulus of 350 units an average of 44 trials was required before errors ceased, with 480 units 21.66

trials, and with 590 units only 16.66 trials. The same relation holds true for medium discrimination and stimuli of 220, 350 and 480 units, but when a stimulus of 590 units was employed the number of trials required for learning to make the discrimination *increased from 40 to 50*. In order to make certain that this increase in the number of learning trials was due only to the strength of the stimulus I repeated the test with a second group of six chicks and the average was practically the same, namely, 46.66 trials. With medium difference of brightness of the two screens, therefore, the optimal stimulus lies nearer the threshold than under the easy condition of discrimination.

The responses of the chicks to the third, or difficult, condition of discrimination are less easy to interpret. With the weakest stimulus used for this condition, 350 units, none of the six chicks failed, with the medium stimulus one failed, and with the strong stimulus two out of five failed. Moreover, the utmost patience was required of the experimenter in order that all should not fail. Each trial also required much more time than in medium and easy discrimination. If, however, we consider only the chicks that learned to make the difficult discrimination the relation stated for easy discrimination appears once more, i. e., the stronger the stimulus the more rapid the learning. It seems clear, therefore, that, with difficult discrimination, the strong stimuli divided the chicks into two groups, (1) those which after a few trials ceased to try to escape and would no longer step on the electric wires, and (2) those which chose with greater and greater caution and, therefore, learned to choose correctly after a small number of trials, each of which consumed much time.

To what shall we ascribe this dual result under the third condition of discrimination? It seemed possible that the chicks were divided into the two groups according to their sensitivity to the electric stimulus. That is, the more sensitive chicks might learn most rapidly under the influence of a weak stimulus, be slow to learn under the influence of a strong one, and fail completely when under the influence of both a strong stimulus and a difficult condition of discrimination.

In order to answer this question twelve chicks were selected of which number six had a threshold of stimulation of 90 units and the remaining six of 150 units (relative values). The former

are designated by the letter s (sensitive) placed after their numbers in table III, the latter by the letter i (insensitive). Tests were then begun with three sensitive chicks, Nos. 61, 62, and 66, and with three insensitive ones, Nos. 63, 64, and 65, under the medium condition of discrimination and with a weak stimulus. Unfortunately, Nos. 63 and 64 died before the tests were completed. No. 65, however, required 150 trials for perfect discrimination while each of the sensitive chicks required exactly 90 trials. The loss of the two insensitive chicks makes a definite conclusion impossible, yet all our work with weak stimuli agrees with the result of the records of these four chicks. It is probable, therefore, that the chicks which were most sensitive to the electric stimulus were the ones which learned most rapidly under the influence of weak stimuli.

Let us turn now to the results of strong stimulation. Should the sensitive chicks be those which failed under the difficult condition of discrimination and strong stimuli they should be slowest to learn with the same stimuli and medium difference of illumination of the two screens, since it was already proved that a strong stimulus increased the learning rate under this condition. Three sensitive chicks (Nos. 67, 68, and 69) and three insensitive ones (Nos. 70, 71, and 72) were, therefore trained under this condition. An examination of their records shows that the sensitive chicks required an average of 40 trials for learning to discriminate between the two screens, while the insensitive ones required 53.33 trials. Evidently, therefore, sensitiveness to the stimulus was not the condition which prevented rapid learning under a strong stimulus.

At the close of these experiments with sensitive and insensitive chicks there seemed to be no explanation for the divergent results under the third, or difficult condition of discrimination. The *behavior* of the chicks indicated, however, that the pain stimulus impressed the memory of those that failed so deeply and permanently that, after a few experiences of it, they avoided the electric wires completely and would no longer attempt to escape from the experiment box. This observation, based on the chicks' behavior, receives striking confirmation from the records. The records of the successful chicks in the group 37-41, inclusive, show that in their first fifty trials each chick received an average of 20.4 pain stimuli, while chick 42, which failed,

received in the first fifty trials 30 such stimuli. These additional stimuli seemed to inhibit completely the impulse to enter the electric passageways. In the case of chicks 56-60, inclusive, only the average number of pain stimuli received during the first forty trials can be considered as chick 56 would not attempt to escape after the fortieth trial. In the first forty trials chicks 57, 58, and 59, which succeeded, each received an average of 15.3 pain stimuli. Chicks 56 and 60 received an average of 20.5 such stimuli *and failed*, while chick 55, which went to the wrong passageway in nine of the first ten trials, flew from the door of escape with such violence that he was injured in alighting. *Those chicks failed, therefore, which made more wrong choices in their early trials and consequently received more pain stimuli than their successful companions.* The additional repetitions of the stimulus seem to have stamped in the impression of the pain and to have caused the failures rather than a native difference of brain plasticity as I had supposed on observing the marked difference of behavior between successful and unsuccessful chicks. Here, as elsewhere, repetition seems to be prepotent in determining memory, if these smooth brained and extremely stupid creatures may be said to have memory. The difference between arousing extremely slow and cautious discrimination and inhibiting all efforts to escape lies, I believe, in the added number of pain stimuli given in early trials to the chicks which failed.

Records were kept of the sex of all the chicks used in the experiments but they revealed no correlation between sex and rate of learning. In fact the slow and rapid learners were distributed rather evenly between the two sexes.

Under the conditions of the experiments, it seemed probable that the heavier chicks received stronger electric stimuli than the lighter ones and therefore learned the more rapidly. But the weights of the chicks of several groups were recorded every three days during the period of experimentation without revealing differences between the heavier and the lighter individuals either in behavior or rate of learning. Again, there was no correlation between weight and sensitiveness to the current in the chicks whose threshold of sensitiveness was determined before training them.

I have shown that, for easy discrimination, increase of the inten-

sity of the stimulus is followed by decrease in learning rate, while, for medium discrimination an optimal intensity of stimulus is found, increase beyond which is followed by slower learning. Thus far my results and those of Yerkes and Dodson in the case of the dancing mouse seem to agree. In the case of the mouse under the difficult condition of discrimination it was found that the optimal stimulus approached much nearer the threshold than with medium difference of illumination between the two boxes. My results with chicks are in conflict with this unless, as has been done, the cases of failure to learn to discriminate are considered. Then it is found that, with the difficult condition of discrimination and the weakest stimulus, *none*, with the next greater strength of stimulus, *one*, and with the strongest stimulus *two chicks failed*. With slight difference of brightness between the two screens the strength of stimulus under whose influence no chicks fail to learn to discriminate is nearer the threshold than the optimal stimulus for the medium condition of discrimination. Perhaps this is as close agreement of the results for mice and for chicks as we should expect to find in animals so unlike. The behavior of the chicks was, however, the reverse of that of the mice. Yerkes writes:⁷ "The behavior of the dancers varied with the strength of the stimulus to which they were subjected. They chose no less quickly in the case of the strong stimulus than in the case of the weak, but they were less careful in the former case and chose with less deliberation and certainty." My chicks, on the other hand, chose quickly with weak stimuli, but only after long delay with strong stimuli. A chick would sometimes require ten or fifteen minutes to make a choice in the latter case.—This difference might perhaps be accounted for by the fact that, with the mouse, a moveable cardboard partition was used by which the space in which the animal could move was gradually restricted. Thus a choice of one passageway or the other was finally necessary. This device could not be used satisfactorily with chicks.

The record of one chick, which appeared to be perfectly normal when I began experiments with it, but died before they were completed, deserves notice. Its training series on successive days were as follows:

⁷ Yerkes and Dodson, loc. cit., p. 476.

Daily series of tests	Choices	
	Right	Wrong
1	5	5
2	8	2
3	9	1
4	9	1
5	8	2
6	8	2
7	9	1
8	7	3

On the ninth day the chick was weak and would not choose either passageway. When I dissected it a large intestinal cyst was found in which there was much food and a fluid secretion. Such a cyst could have formed in a few days. But the important point is that the only sign of ill health in this chick for four days was the *decrease in the number of right choices*. On the fifth day physical signs of weakness appeared.

In conclusion, it is evident that within the limits of the stimuli which I used, the number of trials required by the chick to learn to choose consecutively the darker of two unequally illuminated screens, when discrimination is easy, decreases with an increase of stimulus. Under medium difficulty of discrimination the above law holds true only for the lower intensities of the stimuli which were used, or, in other words, the optimal stimulus recedes toward the threshold from 590 to 480 units. The above law for the condition of easy discrimination holds true for that of difficult discrimination if we consider only the records of the chicks which succeed in learning to make the discrimination. If, however, we consider only the chicks which fail, the optimal stimulus recedes once more to a point nearer the threshold of stimulation than in the case of medium discrimination. In other words, with the difficult condition of discrimination, strong stimuli divide the chicks into two groups, those which succeed in learning to discriminate by reason of more right choices at the beginning of the training series and consequently fewer pain stimuli, and those which fail because of fewer right choices and more pain stimuli in the earlier trials. So far as I determined the sensitiveness of the chicks it may be said that on the average the more sensitive chicks learned more rapidly both for strong and for weak stimuli.

EXPERIMENTS ON TACTUAL SENSATIONS IN THE WHITE RAT

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FOUR FIGURES

The object of the present series of experiments was two-fold: first, to determine if possible the function of the tactual sensations of the white rat in learning a maze; and second, to ascertain the effect of the running of previous mazes upon the learning of subsequent alterations of the original maze by opening and closing definite pathways.

In previous experiments by Watson,¹ it has been shown that any one of the following senses may well be dispensed with by the white rat in learning the maze: (1) vision—one series of rats learned the maze in darkness, and another series with eyes removed; (2) olfaction—the rats having been made anosmic by an operation; (3) audition—sense of hearing temporarily eliminated by filling the middle ear with paraffine; (4) cutaneous sensation so far as vibrissae were concerned—vibrissae closely clipped. While in the above tests no rats were deprived of more than one sense at a time, Watson² also experimented with a young male rat whose vibrissae had been clipped and which at the same time was blind and anosmic. Notwithstanding that a certain lack of tonicity was observable, and that errors were eliminated more slowly, the rat learned the maze, and finally became the usual automaton. It is obvious that while these tests indicate that certain senses are not necessary for learning the maze, they do not show what sense-factors are normally utilized. Further, though Watson³ anaesthetized the nose of an anosmic rat and found that “successive reactions were not in the least disturbed,” this experiment threw no light on the significance of the cutaneous sensations in learning the maze, since the animal had been previously trained. Likewise, although in these cases the vibrissae had been removed

¹ Watson, J. B., Kinaesthetic and organic sensations: their rôle in the reactions of the white rat to the maze. *Psychological Review*, Mon. Sup., vol. 8, No. 2.

² *Ibid.*, p. 98 f.

³ *Ibid.*, p. 77.

and thereby certain cutaneous sensations had been eliminated, the question of the part played by actual nose and head contact in learning the maze remains open. It is this problem which we propose to investigate.

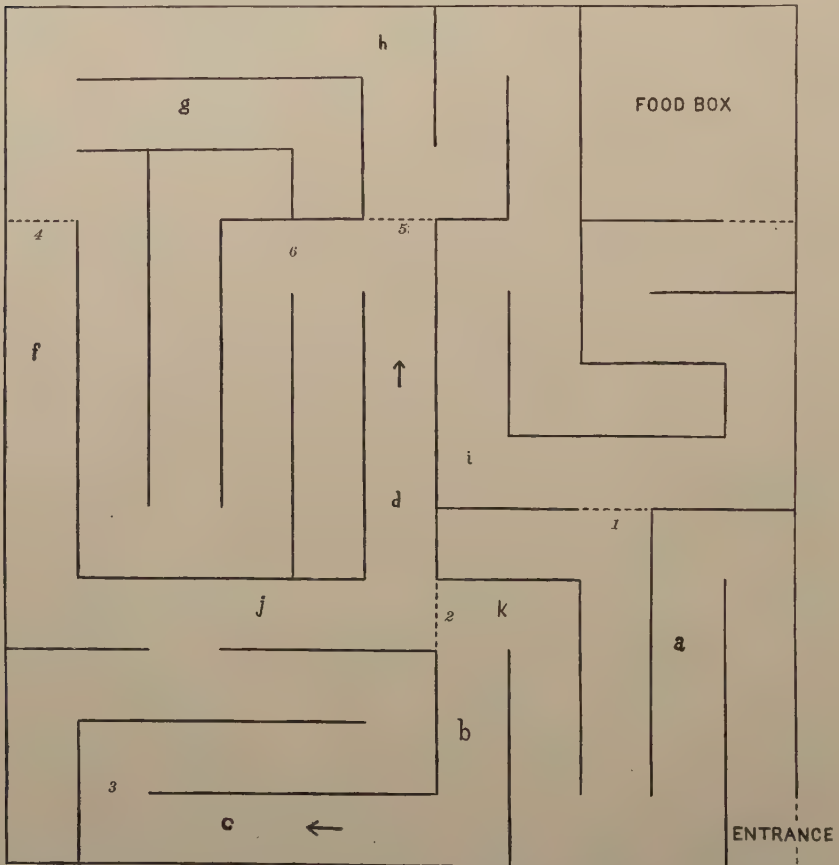
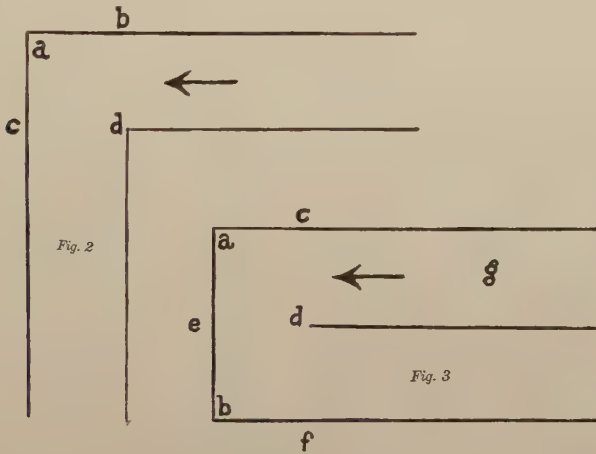


FIGURE 1—Maze I—Doors 3 and 6 open; other doors closed.
 Maze II—Door 5 put at 6; Doors 3 and 5 open, other doors closed.
 Maze III—Door 2 put at 3; Doors 2 and 5 open, other doors closed.
 Maze IV—Door 4 put at 5; Doors 2 and 4 open, other doors closed.
 Maze V—Door 1 put at 2; Doors 1 and 4 open, other doors closed.

The maze used in the following experiments was one with the food-box in the corner instead of at the center as in the Hampton Court maze. The maze was covered with glass in place of the wire netting commonly used in similar experiments.

As indicated in figure 1, the alleys were constructed with removable doors at 1, 2, 3, 4, 5 and 6. In maze I, doors 3 and 6 were open while doors 1, 2, 4 and 5 were closed.

The first set of rats used in this series of experiments were normal animals, two males and three females. They were about three months old, and had never been used in experimentation. They were fed daily in the food-box of the maze until they became thoroughly tame. Their vibrissae were cut off two days before our experiments began. At the end of that time all emotional disturbances had disappeared and the rats acted in a perfectly normal way. This was done in order to facilitate



FIGURES 2 AND 3

the observation of actual head and nose contact in turning the corners of the pathway. No attempt was made in this experiment to keep a record of contacts except at the corners. In general, it was very noticeable, however, that the animals at first kept in close contact with the sides of the pathway.

Reference to figures 2 and 3 will show what we mean by "corners." In figure 2, if a rat touched the corner a at any point between b and c or at d, he was checked up with one corner touched. In no case was a rat checked up with more than one contact for a corner. Likewise, in figure 3, if a rat touched the corner a between c and e or at d he was checked up with one contact; and if he also touched the side of the pathway again between e and f he was checked up with another

contact. The two corners were never represented by more than two contacts. A record was kept of all the corners not touched, as well as of those with which the animals actually came into contact.

Table I shows the average time, the average number of errors,

TABLE I

SHOWING AVERAGE TIME, AVERAGE NUMBER OF ERRORS, AVERAGE NUMBER OF CORNERS TOUCHED, AVERAGE PERCENTAGE OF CORNERS TOUCHED OF FIVE NORMAL WHITE RATS IN LEARNING MAZE I

Number of trial	Average time, in minutes	Average errors	Average number of corners touched	Average percentage of corners touched
1.....	17.73	46.4	51.2	.77
2.....	4.53	16.2	43.4	.70
3.....	1.85	9.2	25.0	.54
4.....	.90	6.8	18.2	.43
5.....	1.32	5.6	22.4	.56
6.....	2.40	15.0	30.0	.52
7.....	.98	6.4	17.0	.37
8.....	.69	4.6	13.6	.37
9.....	1.65	4.4	14.4	.41
10.....	.83	7.2	16.4	.31
11.....	.87	5.8	9.4	.24
12.....	.60	2.4	8.0	.23
13.....	.64	3.0	8.8	.20
14.....	.50	2.0	4.2	.13
15.....	.66	2.6	5.8	.16
16.....	.85	1.2	2.8	.13
17.....	.92	3.2	5.0	.17
18.....	.39	1.2	2.4	.13
19.....	.40	0.4	1.8	.12
20.....	.48	1.6	2.4	.12
21.....	.42	0.8	1.6	.05
22.....	.56	1.2	3.4	.16
23.....	.46	1.4	1.4	.11
24.....	.35	0.6	1.8	.14
25.....	.41	1.0	2.2	.07
26.....	.42	0.4	1.8	.06
27.....	.46	0.8	2.2	.07
28.....	.46	0.2	1.2	.04
29.....	.27	0.2	1.6	.05
30.....	.36	1.0	1.8	.06
31.....	.36	0.4	1.0	.03
32.....	.31	0.0	1.4	.05
33.....	.31	0.4	0.8	.02

the average number of corners touched, the average percentage of corners touched, of the five normal rats in learning the maze. Reference to the table reveals the following facts:

(1) The percentage of corners touched is high at the beginning

and gradually decreases as the maze is learned. The first figures, while high, do not render full justice to the situation. Figure 3 will serve to illustrate the point. When the rat came down alley g toward a, one contact at any point in the vicinity of e

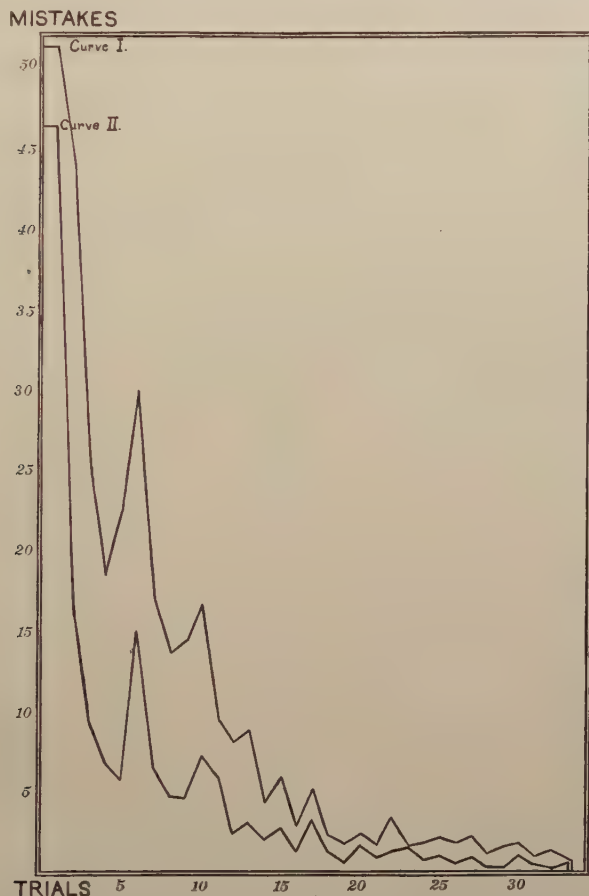


FIGURE 4—Constructed from table I. Curve I.—Graphic representation of number of corners touched in learning maze I by five normal rats. Ordinates represent number of corners touched; abscissas represent number of trials. Curve II.—Graphic representation of errors under above conditions. Ordinates indicate the number of errors.

might serve as a sufficient stimulus to make the turn successfully. Thereby the rat went around two corners with only one contact. Had the corners been farther apart, two contacts would probably have been made, since this was usually the case.

In other words, since two corners have been turned with only one contact, the rat has been checked up with only fifty per cent. of contact in these cases. Inasmuch as the two corners were so close together, they became one to the rat, and the fifty per cent. in such instances really represents one hundred per cent. of contact. Our method of counting the corners as given above was due to the fact that often the rats actually touched both corners. It was not feasible sometimes to count two corners as one and sometimes as two. Since there are a large proportion of these double corners in the normal pathway of maze I, the percentage of the corners with which the rat came into contact has been lowered considerably by our method of enumeration; ninety per cent. probably is not too high an estimate for the first run. This seems to indicate that in acquiring the kinaesthetic and organic sensations which the rat later utilizes in running the maze, tactual sensations are more important than smell or vision.

(2) In the second place, the table shows that there is a striking correlation between the number of corners touched and the number of errors. Curves I and II, fig. 4, give a graphic representation, making the correlation more obvious. This indicates that as soon as the running ceases temporarily to be automatic and errors are made, the number of contacts forthwith is increased and tactual sensations are used until the animal has run at least a unit of the maze and the automatic kinaesthetic and organic control is re-instated.

(3) There is also a general correlation between the increase and decrease of time and the number of contacts. In run 4 (see table I) the average time was .90 minute and the number of contacts 18.2; in run 6, the average time rose to 2.40 and the contacts rose to 30. The rise in time at the ninth run is accounted for by the fact that rat 5 halted and took four minutes to run the maze. This correlation is in harmony with the theory that tactual sensations are of first importance in *learning* the maze.

(4) The table shows that when the maze is learned, contact at the corners is no longer necessary. According to our observations, what holds true of the contact at the corners applies to the contacts with the sides of the pathway between the corners.

After the five normal rats had learned maze I, six female

blind rats were trained to run the maze. These rats had some time previously learned a different maze. They were run in maze I only until each individual had learned the maze for herself. Average results were secured for twenty-one runs, as indicated in table II. These results, while obtained under different conditions, bear out, as far as they go, the four conclusions given above, and especially add weight to the contact theory of ac-

TABLE II

SHOWING AVERAGE TIME, AVERAGE NUMBER OF ERRORS, AVERAGE NUMBER OF CORNERS TOUCHED AND AVERAGE PERCENTAGE OF CORNERS TOUCHED OF SIX BLIND RATS FOR THE FIRST TWENTY-ONE RUNS OF MAZE I

Number of trial	Average time, in minutes	Average errors	Average number of corners touched	Average percentage of corners touched
1.....	7.89	31.6	69.5	.63
2.....	1.84	14.8	34.8	.61
3.....	1.17	5.6	18.5	.43
4.....	3.16	24.5	40.8	.40
5.....	1.39	5.1	15.5	.38
6.....	.86	7.5	16.3	.32
7.....	.68	2.1	6.5	.19
8.....	.78	4.3	7.1	.19
9.....	.99	7.3	11.1	.17
10.....	.50	1.8	4.6	.17
11.....	.56	2.1	4.8	.14
12.....	.49	1.5	4.6	.19
13.....	.35	0.6	1.0	.03
14.....	.38	1.8	2.3	.07
15.....	.35	3.1	1.1	.03
16.....	.51	1.8	3.8	.12
17.....	.66	1.0	4.0	.12
18.....	.48	2.1	2.5	.07
19.....	.61	3.3	4.5	.08
20.....	.50	2.5	2.3	.06
21.....	.53	0.1	4.1	.12

quiring the kinaesthetic-organic cues. We also subjoin a typical table (III) of an individual blind rat, which will likewise serve to corroborate our conclusions.

Moreover, the percentage of contacts as shown in tables II and III does not begin so high as in table I, and throughout the learning process it remains lower. This indicates that the rats were probably influenced by the previous learning of a maze. One of the most obvious factors doubtless was that the blind rats did not have to learn that there was food in the food-box. Furthermore, they were accustomed to running a not entirely dissimilar maze.

After the five normal and six blind rats had learned maze I, they were taught mazes II, III, IV, and V (see fig. 1) in succession. Our object here was to study the function of the contact sensations in making readjustments to slightly altered conditions. The same general results obtained. All rats became confused in the new situation and were forced to make a new adjustment by the trial and error method. During the period of confusion the animals fell back upon the use of contact sensations and continued to rely upon them until they reached a familiar unit in the maze. The number of contacts again varies with the number of errors made. Table III gives a typical detailed record for a blind rat.

In bringing to a close this description of the experiments, it is evident that tactual sensations of the nose and head are utilized in learning the maze, and this implies that they are used in getting the kinaesthetic and organic cues. The facts which we offer in substantiation are: (a) the percentage of corners touched, beginning high, gradually decreases as the movements of the rat become automatic; (b) a striking correlation exists between the number of contacts and the number of errors; (c) a general correlation between increase and decrease of time, and of the number of corners touched; (d) tactual sensations are no longer used when the maze is learned; (e) when the kinaesthetic and organic cue is lost at any point in the maze, the rats rely upon head and nose contact; (f) the conclusions hold for both normal and blind animals and indicate a minimal effect of vision.

As indicated, the maze used in this experiment was constructed so that the pathway could be altered in various ways. This type of construction was designed for the purpose of studying the effects of the maze experiences upon subsequent behavior in slightly altered conditions. While our experiments were concerned primarily with the function of contact sensations in learning to make adjustments to new or slightly modified situations, yet they yielded some incidental results bearing upon the former problem which are of sufficient interest to merit a short discussion.

A reference to fig. 1 will show the successive alterations effected. In maze II, door 5 was placed at 6, while door 3 was opened. Maze II was altered by placing door 2 at 3 and by opening 5.

TABLE III
SHOWING TIME, ERRORS, PERCENTAGE OF CORNERS TOUCHED, AND NUMBER OF CORNERS TOUCHED FOR RAT B,
(BLIND) IN RUNNING MAZES I, II, III, IV AND V

Number of run	Time, in minutes					Errors					Percentage of corners touched					Number of corners touched				
	Maze					Maze					Maze					Maze				
	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
1.....	8.33	.37	.37	2.75	.83	42	2	2	6	31	15	.61	.14	.18	.47	94	5	6	45	18
2.....	.75	.83	.30	.22	.20	6	6	7	2	3	3	.41	.20	.22	.13	13	8	7	4	7
3.....	.83	.25	.25	.67	.17	4	1	4	7	3	3	.25	.08	.10	.28	8	2	2	12	7
4.....	1.08	.25	.17	.25	.17	3	2	3	2	4	4	.30	.12	.00	.26	11	3	0	6	7
5.....	.80	.27	.20	.20	.33	2	2	3	2	6	6	.39	.11	.12	.28	13	3	3	7	8
6.....	.50	.38	.17	.15	.23	4	2	2	1	2	2	.24	.21	.04	.11	8	8	1	2	6
7.....	.33	.25	.17	.17	.17	2	0	2	0	3	3	.09	.08	.04	.06	47	3	2	1	8
8.....	.42	.17	.25	.50	.13	3	3	0	2	1	2	.12	.04	.09	.24	4	1	2	5	4
9.....	.42	.20	.13	.17	.13	2	0	0	0	2	2	.03	.08	.00	.10	1	2	0	2	5
10.....	.33	.17	.13	.25	.25	1	1	0	1	5	5	.06	.00	.00	.17	2	0	0	3	6
11.....	.75	.13	.13	.20	.17	2	2	0	1	2	2	.23	.00	.00	.19	7	0	0	4	5
12.....	.30	.17	.25	.20	.13	0	0	0	2	1	2	.06	.08	.10	.05	2	2	2	1	6
13.....	.33	.15	.17	.15	.15	0	0	0	1	1	5	.00	.00	.00	.05	31	0	0	1	5
14.....	.30	.15	.12	.28	.13	0	0	1	0	2	2	.07	.00	.00	.21	27	2	0	4	4
15.....	.23	.13	.13	.25	.25	0	1	1	0	4	4	.00	.00	.00	.41	0	0	0	0	7
16.....	.17	.17	.13	.17	.13	0	0	1	0	2	2	.14	.00	.21	.00	0	3	0	4	4
17.....	.50	.17	.58	.13	.13	0	0	0	0	2	2	.13	.00	.04	.20	4	0	0	7	3
18.....	.67	.10	.20	.13	.13	1	0	0	1	2	2	.10	.00	.10	.00	3	0	2	2	0
19.....	1.83	.17	.20	.10	.10	13	0	0	1	2	2	.34	.00	.05	.08	22	0	1	1	1
20.....	.37	.13	.50	.08	.08	0	0	0	1	2	2	.07	.00	.05	.08	2	0	0	1	1
21.....	.50	.08	.67	.10	.10	0	0	0	2	2	2	.03	.00	.23	.14	1	1	5	2	2
22.....	.58	.17	.50	.08	.08	0	0	0	2	2	1	.13	.05	.17	.14	4	1	4	2	2
23.....		.17	.17	.13	.13	0	0	0	0	0	1	.00	.11	.00	.14	2	0	2	0	2
24.....		.12	.20	.13	.13	0	0	0	0	0	1	.11	.00	.14	.16	0	2	2	0	2
25.....		.08	.17	.13	.13	0	0	0	0	0	1	.11	.16	.16	.16	0	2	2	0	2
26.....		.17	.20	.17	.20	0	0	0	0	0	1	.00	.22	.22	.22	0	0	4	4	3
27.....		.17	.25	.17	.25	0	0	0	1	3	3	.05	.05	.05	.20	1	1	1	1	1
28.....		.20	.12	.20	.12	0	0	2	1	2	2	.05	.08	.05	.08	0	0	0	0	0
29.....		.17	.08	.17	.08	0	0	2	0	2	2	.00	.00	.00	.00	0	0	0	0	0
30.....		.13	.08	.13	.08	0	0	2	0	2	2	.00	.00	.00	.00	0	0	0	0	0
31.....		.13	.08	.13	.08	0	0	2	0	2	2	.00	.00	.00	.00	0	0	0	0	0
32.....		.17	.08	.17	.08	0	0	2	0	2	2	.00	.00	.00	.00	0	0	0	0	0
33.....		.07	.07	.07	.07	0	0	2	0	2	2	.00	.00	.00	.00	0	0	0	0	0
34.....		.08	.08	.08	.08	0	0	2	0	2	2	.00	.00	.00	.00	0	0	0	0	0
35.....		.08	.08	.08	.08	0	0	2	0	2	2	.00	.00	.00	.00	0	0	0	0	0
36.....		.08	.08	.08	.08	0	0	2	0	2	2	.00	.00	.00	.00	0	0	0	0	0

This third maze was altered by placing door 4 at 5 and by opening 2. The fourth maze was changed by placing door 1 at 2 and by opening 4. Several important features are to be noted in this series of mazes. (1) Mazes II and III merely shorten successively the true pathway of maze I. The object here is to observe the process of learning to short circuit a familiar path. This short circuiting is not optional on the part of the animals, inasmuch as the former roundabout path has been blocked by the insertion of sliding doors. (2) In mazes IV and V, the animals are forced to enter former blind alleys at the end of which they find themselves upon the old familiar path. (3) All five mazes possess a common or identical true pathway at the beginning and at the end. The mazes differ from each other only in the middle portion. Each maze differs from the preceding one only in one respect, so that each succeeding maze requires the animals to make but one new adjustment. This position may be termed the critical point. In mazes II and III the rats travel the habitual path for a certain distance and then are forced by a short cut to strike the old path which they can follow to the end. In mazes IV and V, the animals travel at first over the old path; from this they are forced into a blind alley at the end of which they emerge again onto the old path. In describing the rats' behavior in making these adjustments, we shall need to refer to these three parts of the pathway.

These mazes were graded for relative difficulty in learning in the following order: I, II, IV, III, V. By relative difficulty we mean the order of difficulty which would be encountered by animals with no previous maze experiences. This order was not determined by actual experiment, but was based upon judgments of their apparent complexity. That mazes III and V are much simpler than maze I is evident at a glance.

The actual order of difficulty encountered in learning them successively was V, IV, III, I, II. This fact is illustrated by table III, the results of which are typical for all of the rats used. This order is almost the reverse of that of their relative complexity. In the successive learning of a series of similar mazes, it is evident that previous experiences are effective upon subsequent behavior and that these effects are advantageous or disadvantageous according to circumstances.

As one would expect, the animals ran over the first identical

portion up to the critical position without error or hesitation. Evidently their previous learning of this path is of service in the altered maze. As a rule the animals did not make an immediate adjustment at the critical position but ran on over the old path until they found the pathway blocked. This blocked pathway forced a readjustment of the trial and error sort. In this process the rats tended to confine their explorations to the old pathway, running back and forth between the inserted door and the entrance of the maze. The old habits thus tended to confine and limit the exploring activity within certain channels. This limitation of a free and wide excursion of adjustive trials operated to postpone the successful chance adaptation at the critical turn.

On emerging upon the true path after making the successful adjustment, the rats never picked up the cue immediately. The old habit was never reinstated until several alleys were traversed. In the majority of cases the rats left the true path at the first opportunity. The significant feature of their behavior at this point consists in the fact that this deviating turn is generally in the same direction (relative to the rat) as that of the turn which the animals would have made in the previous maze after passing the critical point. A detailed description of their behavior will illustrate this proposition. In maze II, the animals are forced by door 6 into alley 5. Instead of turning to the right immediately, they ran on to corner h and turned to the left. This leftward turn is the normal behavior at corner 5 in the previous maze. In maze III, the critical position is at door 2. Formerly the animals made a turn to the left at this point. After passing through door 2 the rats often attempted to turn to the left and were forced up alley j. This type of behavior did not obtain in the majority of cases. In maze IV, the previous path through 2 and down alley d was closed by the door at 5. The animals had learned to turn immediately to the right after traversing this alley. After emerging through door 4, this persisting tendency to turn immediately to the right led the animals into one of the blind alleys rather than into alley h. In maze V, the rats were forced to substitute the alley leading to door 1 for alley k. Almost invariably the animals turned to the left after emerging through door 1 just as they had habitually done at the corner k. The old habits acquired in the first part

of the maze thus operate disadvantageously in learning similar mazes by tending to prevent the animals from picking up the true path after emerging from the critical part. This disturbance was the most pronounced and persistent in the case of the fifth maze.

After the animals once succeeded in picking up the old familiar path, they almost invariably ran the rest of the maze without error or hesitation. Evidently the presence of a common portion constituting the last part of all the mazes is a highly advantageous feature.

Since each maze differs from the preceding one in but one respect, the question arises as to why the successive adjustments should vary so enormously in difficulty as is evident in table III. The determining conditions are probably very complex though some of the factors were evident from the animals' behavior.

1. Other factors being equal, that maze is the easiest in which the critical position is placed nearest to the entrance. Since the last common portion operates as an advantage, the longer this part the easier should the maze become. In making the readjustment, the animals run back and forth over the first common portion. Evidently the chances of making the correct adjustment is favored by a short runway. The shorter is this segment, the more is their activity centered around the region of the critical position.

2. The adjustments which involve entrances into former *cul de sacs* are more difficult than those which involve a short circuit. The truth of this proposition is evident in table III, and the reasons therefor are obvious. An entrance into an alley which has been effectively eliminated involves a greater violation of past habits than does a mere deviation from the accustomed path. In the latter case there is also present the enticing possibilities of a novel stimulus.

3. The difficulty is increased in proportion to the distance beyond the critical point at which the former path has been blocked. In maze II the path was blocked at 6 while the opening was at 5. On being stopped at 6 the rats explore around in this vicinity before starting back at full speed and as a consequence it was an easy matter to chance upon door 5. In maze III the path was blocked at 3 while door 2 was open. On encountering the closed runway at 3, the animals investigate for

a while in that vicinity, and then run back and forth between this point and the entrance, stopping here and there to investigate. The chances of discovering the open door at 2 seem to be minimized in proportion to the speed of running at this point. At least, stopping to investigate in this region is more likely to lead to successful results than will high speed. In maze III the rats tended to run rapidly by the opened door and it thus escaped their notice. If the path had been so blocked that the rats were forced to stop in the immediate vicinity the chances for the detection of the opened door would have been increased.

Since all of the mazes were identical except for the critical portion in the middle, it is surprising that this one act of adjustment should be so difficult in comparison to maze I which was learned *de novo*. The first maze presents a whole series of critical positions while each succeeding maze presents but one. Viewed in this light, it seems that the disadvantages of the old habits rather overshadow their advantages.

The difficulty of short circuiting even under the most favorable conditions as in maze II is rather surprising. In all probability much poorer records would have been made if the short circuiting had been optional rather than compulsory. It would seem that the animals are guided but little by the smell of their own path.

The fact that the removal of doors 2 and 5 at the end of a runway failed to attract the rats' attention indicates that these animals do not rely to any great extent upon stimuli coming from impending walls in order to negotiate a turn. This fact harmonizes with Watson's contention that these turns are negotiated mainly upon a kinaesthetic and organic basis. In this connection, however, it was noted that the blind animals ran into the doors used to block the old path with more strength and persistence than did the normal rats.

THE RELATIVE VALUES OF THE DIFFERENT CURVES OF LEARNING

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FIVE FIGURES

There are three possible quantitative criteria which can be used in representing the learning process of an animal in the maze, viz., the number of errors, the time of the run, and the total distance traversed. Time and error data have been used, but a distance curve has never been published. It is our purpose to discuss the relative values and limitations of these three criteria as representative of the learning process in the light of an experimental study in which the three sets of data are taken for the same group of animals.

There has been a divergence both of opinion and practice in regard to time and error criteria. Some experimenters publish only error results, while others rely upon time alone. Two antagonistic opinions have been expressed by Watson and Yerkes. Watson ¹ takes a very decided stand in favor of time as a criterion, as is evident in the following passage: "There is one serious defect in the Small maze. We find it impossible to take an accurate account of the errors in it. As a matter of fact, we have recorded the errors made by our rats in the way suggested by Small, Kinnaman and Porter. They fill one or two notebooks, but we feel sure that they are not worth the time spent in recording them—certainly are not valuable enough nor accurate enough to publish. Since this position makes the absolute time record the only criterion of the learning process, we have used extra precautions to make it show what it is meant to show, viz., the relative rapidity with which normal and defective rats form the maze association. We have both time and error records before us, and we unhesitatingly say, that the time record carefully controlled, is the only safe guide to estimating the learning process of a maze constructed along the lines of the present one."

¹ Watson, J. B., *Kinaesthetic and organic sensations: their rôle in the reactions of the white rat to the maze. Psychological Review, Mon. Sup.*, 1907, vol. 8, No. 2, pp. 13-14.

On the other hand, Yerkes² in the following passage is quite as unqualified in his approval of the error method of estimating learning. "Time records are not reported for these and subsequent labyrinth tests because they proved to be almost valueless as measures of the rapidity of habit formation. At any point of its progress through the labyrinth, the dancer may suddenly stop to wash its face, look about or otherwise examine its surroundings; if a shock be given to hurry it along it may be surprised into an error. It is my experience, and this is true of other animals as well as of the dancing mouse, that a long trip, as measured in time units, does not necessarily indicate the lack of ability to follow the labyrinth path accurately and rapidly. Hence, whenever it is possible (and the experimenter can always plan his tests so that it shall be possible), the number of errors should be given first importance and the time of the tests second place."

Apropos of our general problem, we wish to urge in the first place that the relative value of any two criteria may depend upon circumstances, and that no dogmatic statements applicable to all conditions can be made. Consequently, any general conclusions we may reach in this paper must be understood as limited to the white rats and to the problem of the maze. Yerkes in the passage quoted suggests that the value of a criterion may depend upon the nature of the animal used in the experiment. However this may be, it is undoubtedly true that the nature of the problem must influence the choice of a criterion. Watson in the passage quoted apparently recognizes this fact. The contention is evident from the consideration of a few illustrations. In a maze with no *cul de sacs*, the possibility of an error curve (when errors are confined to entrances into the *cul de sacs*, as is usually the case) is eliminated, and time is the only criterion. It may be contended that such a hypothetical maze will present no problem to an animal, and hence that no learning process can exist to be represented. This contention is emphatically disproven by an experiment conducted in this laboratory by Misses Hybarger and Cowles with a maze in which all *cul de sacs* were closed. Two groups of six rats each were used. The average time for the first trial was 6.42 minutes, and this time was gradually decreased for twelve runs. The time results are represented graphically by curve II of fig. 4. The

² Yerkes, R. M., *The Dancing Mouse*. New York, 1907, pp. 217-8.

of its interpretation and its value relative to that of the distance curve. Such a curve will represent grossly the elimination of certain distances.

Time varies directly to a great extent with distance, and hence it represents to some extent the same factors of the learning process as does error or distance. However, it has often been noted that time and distance also vary independently of each other. This fact is so patent that illustrations are unnecessary. We wish at this time merely to emphasize the point that this fact of the independent variability of time and distance is at

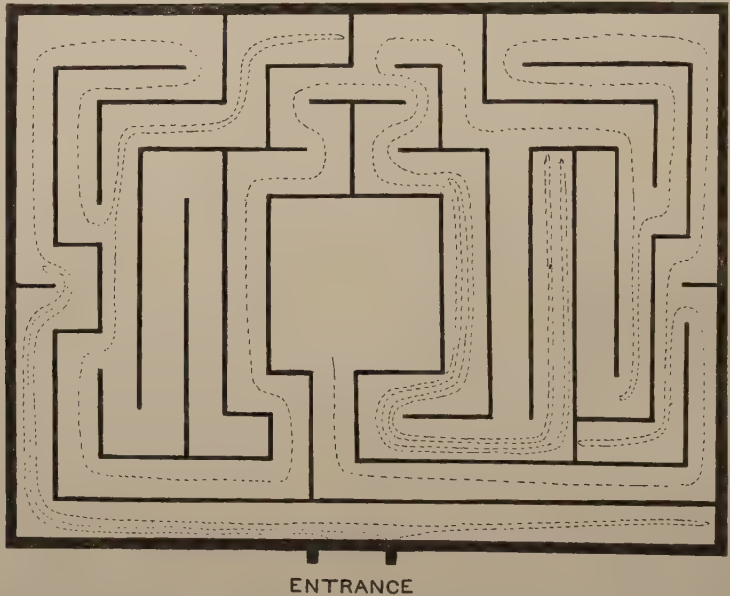


FIGURE 1—Path followed by rat No. 2 in its fourth trial, April 26, 2 p. m.
Time, 4 minutes, 2 seconds.

the basis of the whole problem of the relative value of those two criteria, and it is our purpose before proceeding further with the discussion to ascertain by experimental means the exact extent to which these two factors do vary.

Seventeen white rats in three groups were given a total of 591 runs in a Hampton Court maze. They were run daily by the same person at approximately the same time of the day. Hunger was used as a motive, and an attempt was made to secure uniform conditions by allowing the animals to eat for a definite

period of time each day. Before the experiment the rats were accustomed to being handled and fed in the food box in the maze.

In the time records, the preliminary period of nosing about was eliminated. The time was recorded from the moment that they started out from the entrance box until they reached the entrance to the food box. Time consumed in stopping during the course of the run was not eliminated.

All parts of the maze were divided into small segments of 6 inches, and all corners, runways, and segments were labelled according to a logical scheme. This system of labels was outlined on a large chart which hung in plain sight, and in this manner the experimenter was enabled to jot down an accurate representation of each run in all of its devious details. The error and distance records were computed from these symbolic records. Over one hundred of these runs were reproduced graphically in the manner depicted in figure 1. These permanent graphic records are invaluable for the study of certain qualitative features of the learning process.

In computing the number of errors, some position must be assumed as to the questions previously raised regarding the definition of an error. We were guided by two general propositions:—

1st. Errors shall include all total and partial returns as well as entrances into the blind alleys.

2nd. A runway, viz., the distance between two corners, was taken as the unit of error.

The first proposition is supported by the experiment of Misses Hybarger and Cowles upon a maze with no *cul de sacs*. Returns constitute the only possible errors. The experiment proves that the elimination of the blinds constitutes only a part of the maze problem. The number of returns made is given in table 1, and they are not so numerous in such a case as with a maze with *cul de sacs*. Unless returns are counted, the error curve necessarily does not fully represent the learning process. Observation of the rat's behavior indicates that these returns are an essential and necessary feature of the learning. Apparently, the animals sometimes become confused or lost, and they wander about until by chance they return to a point in the true path that gives them the proper cue. Their behavior strongly suggests that they learn the maze by segments, and after exploring

a new segment, they feel constrained to return to old and familiar landmarks in order to relate the new part with those parts with which they are familiar.

The second proposition was accepted for several reasons. Blinds differ in complexity and ease of learning, and it seems appropriate to attempt some quantitative evaluation. A rat that is lost and wanders hopelessly around until it returns to the entrance box is surely guilty of a greater error than in the case it returns but a short distance before getting its bearings. Evidently the animal knows more about the maze in the latter case. An animal may get lost in a complex blind and wander about hopelessly. Surely this represents a greater error than in the case the animal keeps its bearings and returns immediately to the true path after exploring the blind. Watson has advanced the thesis with a high degree of probability that each runway with its entrance corner forms a characteristic kinaesthetic unit which is the stimulus for the adaptive behavior to the succeeding runways. The adoption of the runway as the unit of error is a logical outcome of such a conception. This view emphasizes the value of all turns or corners as characteristic landmarks in the process of learning. Consequently an animal is checked with an error whenever it makes the turn necessary to enter an alley irrespective of the distance entered up to the first turn. A year's observation of the behavior of the rat in the maze has strengthened this conclusion in the writer's mind. A study of the graphic representations of the trials reveals the fact that the turns are critical points in learning. The rat usually turns or halts at the corners. When the animal becomes confused, he generally picks up his cue at or near some corner.

Curves representative of the three sets of data must be equated, or reduced to some common denominator before any comparisons are valid. There is much that is arbitrary in any graphic representation of the learning process. For example, a time curve can be constructed either "steeped" or "flat" from the same set of data. The ordinate unit must be assigned an arbitrary time value and it is evident that a more steeped curve will result when the ordinate unit represents ten seconds than in the case the ordinate unit is assigned a value of sixty seconds. To avoid any purely arbitrary results, units of time, distance, and error must be equated so that an ordinate unit will represent equivalent values for the three sets of data.

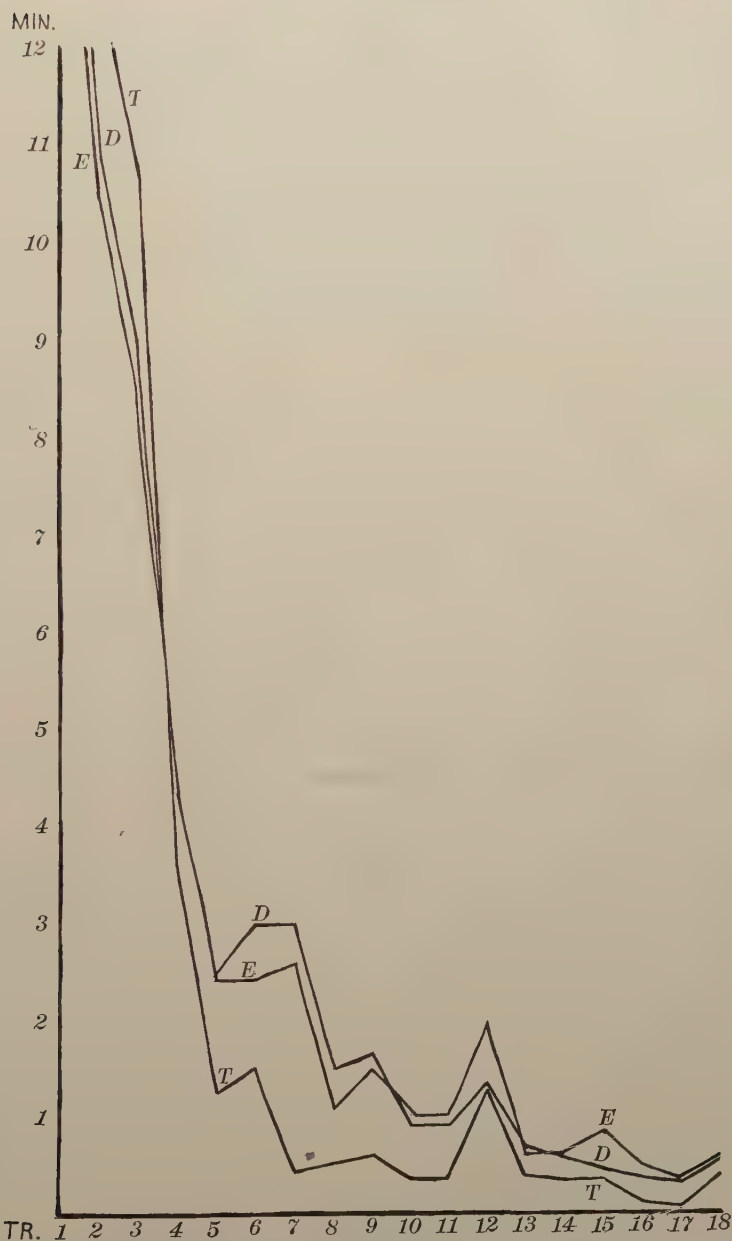


FIGURE 2—Time, error, and distance curves (T., D., E.) based upon the results for seventeen normal rats. *id.*

This equation was performed as follows: Since $13\frac{1}{3}$ seconds represents the average time taken to run the maze correctly (in the experiments described in this paper), all time values above this represent the time consumed in eliminating errors. Thirteen and one-third seconds was subtracted from the time of each run and these remainders were summed, giving the total surplus time eliminated during the experiment. This eliminated time was divided by the total number of errors made with the result that one error was found to be equivalent to thirteen seconds of time. Likewise, 465 inches, the length of the true path, was subtracted from the length of each run and these remainders were summed, giving a value representing the total amount of unnecessary distance eliminated. This surplus distance was divided by the surplus time, giving three inches of distance as equivalent to one second of time. An arbitrary ordinate value was assigned to each error, and this ordinate unit according to the above calculations is also equivalent to thirteen seconds, and to thirty-nine inches. The three curves constructed on this basis are represented in figure 2.

The three sets of data can also be equated on a percentage basis. As before, only the surplus or eliminated values are considered. For example, suppose the time of the first run is twenty minutes and this time value is progressively decreased to zero. The percentage method attempts to represent the rapidity of this decrease irrespective of the absolute values. The time values for the various runs are each divided by the time of the first run. This gives a series of percentage values decreasing from 100 to 0. The value for any trial represents the percentage of time yet to be eliminated, and hence a curve constructed from these decreasing values will represent graphically the rapidity of elimination. Percentage curves are likewise computed and constructed from the distance and error data. Any difference between the curves represents a difference in the relative rate of elimination. Our data were computed by such a method, and the results were compared with the curves constructed by the previous method. According to the percentage method, all curves will begin and end at the same levels, viz., at the 100 and 0 values respectively. According to the first method, the three curves will begin at different levels, but terminate at the zero point. This fact is irrelevant, however, for comparative purposes. Both methods give identical results.

The error and distance curves are practically identical with exception that the error curve is the more irregular and variable. This coincidence experimentally confirms our previous statement that the error curve must approximate the distance curve as a limit when returns are included in the error record and when small segments of the maze are taken as the unit. The slight divergence between the two exemplifies the fact that runways are not eliminated as wholes but progressively. The distance curve thus represents more adequately the details of this eliminative process inside an alley. The two curves so closely coincide, however, that errors, according to our definition, may be regarded as a practicable substitute for distance. This fact is important in view of the many difficulties involved in recording and manipulating the distance data. It is evident that a marked divergence between the two curves must result when errors are confined to *cul de sacs* and no attempt is made to evaluate different degrees of error. A curve constructed according to the older practice cannot adequately represent the progressive elimination of surplus distance.

An inspection of the curves reveals the nature and extent of the independent variability of time and distance. These variations may be classed as either gross or minute. 1. The gross variations consist of a very rapid decrease of time relative to distance during the first eight or nine runs. From this point on to the twenty-fifth trial, distance is eliminated slightly faster than time. After the twenty-fifth trial, any variability is too small to be of importance. 2. Minute variations of a very irregular character occur throughout the entire length of the curves.

The gross variations force one to the conclusion that time and distance represent either different features of the learning process, or else the same features to varying degrees. An analysis of the maze problem and an observation of the rat's behavior indicate that the maze presents to the rat four factors to be learned: first, the elimination of errors; second, the inhibition or elimination of the natural tendencies of timidity and curiosity in new situations; third, the association between food and the maze; fourth, increased speed of running. We wish to advance the propositions that the gross difference between time and distance is due to the fact that distance represents but one of these factors, while time represents all four, and hence that the

time curve is most representative of the learning process. That the time curve actually does represent in some way the factor of error elimination is too obvious for comment. The only debatable point is the assumption that the last three factors noted are essential parts of the total process and should be adequately represented by a learning curve.

When rats are first introduced into the maze, their behavior is dominated to a large extent by curiosity and timidity; their activity exhibits a random and purposeless character. No association has as yet been established between the maze experiences and the satisfaction of hunger. In human terms, the animals have not yet learned that the maze means food and that work will obtain it. After a few trials, the character of their behavior becomes noticeably altered. It is less random and sporadic, and more earnest, purposive and focalized. The transition to eager energy and alertness is very noticeable. The change may be reflected in the error curve, though not very adequately. The random character results in a large number of errors, but the number is not proportionately decreased with the change, inasmuch as the eager energy may operate to increase rather than to decrease the errors. Increased speed per unit of distance is the most obvious result of this change of behavior, and time values may be cut in two without any diminution of errors or distance travelled. This aspect of the learning process is reflected adequately only in the time values, and this fact accounts partly for the rapid decrease of the time curve relative to the error curve during the first few trials. That the formation of this association is a genuine and independent factor of the total problem is axiomatic in character. Without it, the elimination of errors would not occur, and any curve which fails to represent it adequately is false in character.

After the evident formation of this association as judged by behavior, time is still decreased relative to distance. At first the rat does not dare to run as fast as possible or he would bump into the sides and ends of the alleys. He is forced to run slowly and cautiously through the necessity of keeping in contact with the walls, and sensitively alert to impending corners and other familiar landmarks. Alternating moments of hesitation, periods of slow progress, and periods of sudden bursts of speed are

noticeable characteristics of a stage in the development. The animal is progressively freed from this necessary dependence upon objective conditions, and learns to run free. In sensory terms, we might describe this as a change from contact to kin-aesthetic means of control. The progressive freedom from objective limitations results in a decrease of time per unit of distance. The process is both logically and factually independent of that of distance elimination, and it accounts to a large extent for the fall of the time curve relative to that of distance. The importance of this factor becomes evident by stating the situation in anthropomorphic terms. After the formation of the association, the prime object of the rat is to obtain food, and to obtain it as quickly as possible. During the first stage of the learning, his attention is preoccupied with speed exclusively and his best efforts are devoted to polishing off this aspect of his behavior. Elimination of errors occurs but only incidentally. This feature of the problem is subsidiary to the main purpose, and consequently it could emerge into the focus of attention only in the later stages of the learning process. The prevalent insistence upon the prime importance of errors is due to the fact that the problem is envisaged from the point of view of the experimenter rather than from that of the rat. In human psychology, increasing speed is regarded as essential a characteristic of progress towards automaticity as is increasing accuracy and there is no valid reason for not so regarding it in animal behavior. In so far as speed varies independently of accuracy, it should be reflected in any curve that purports to represent adequately the steady progression of any act towards automaticity.

Timidity and curiosity are natural tendencies of a rat in new surroundings, and these tendencies must be overcome, or inhibited, before their trials become automatic. Timidity finds expression in slow, cautious behavior; it also probably accounts for many of the partial and total returns, a fact which supports our proposition that these returns should be included in the error records. Curiosity attracts rats into the blinds and leads them to explore carefully every crook and corner of the true path. These tendencies are overcome largely by the progressive establishment of the association between the maze and the satisfaction of food. To this extent they represent the obverse side of the factor of

association discussed in a preceding paragraph and need no further comment. The curiosity factor, however, is present long after the association has been established, and after errors are largely eliminated. It often leads the animal into the *cul de sacs* which were eliminated in an early stage of the experiment, and consequently this feature finds expression in all three curves. The tendency also causes the animal to stop and examine parts of the true path even after its behavior has approximately reached the automatic stage. The time of the run may often be doubled or tripled in this manner, a result that is represented only by the time curve. This feature of their behavior probably is partly responsible for the later rise of the time curve relative to error and distance. It may be urged that the elimination of curiosity and timidity constitutes no part of the maze problem *per se* and hence should not be represented. This contention is erroneous for two reasons: First, the whole problematical situation cannot legitimately be conceived as confined to the maze alone. The problem is one of adaptation of an animal with a given nature to the maze. If the nature of the animal is entirely eliminated, comparative psychology is without point. The purpose of any experiment is to investigate the ability of a certain animal to learn a given problem, and all native peculiarities, either advantageous or disadvantageous to the process, must be considered. Second, the tendencies cannot be eliminated even if desired. Their results, as already shown, are partially reflected in both the error and distance curves. If these features are to be represented at all, they should be represented as adequately as possible.

The assumptions that these three factors account for the gross differences between the time and distance curves and that they are essential elements of the learning process are supported by curve II, figure 4. This represents the learning by twelve rats of a maze with no *cul de sacs*. With the exception of the returns, the three hypothetical elements mentioned are the only factors of the problem. The error and time data are given in table I. That a real problem is presented to the animals is evident at a glance. More than a third of any maze problem is constituted by the factors under consideration. It is noteworthy that this maze may be regarded as learned in the region of the twelfth trial, which approximates the position at which time ceases to decrease relative to distance in the original experiment. Accord-

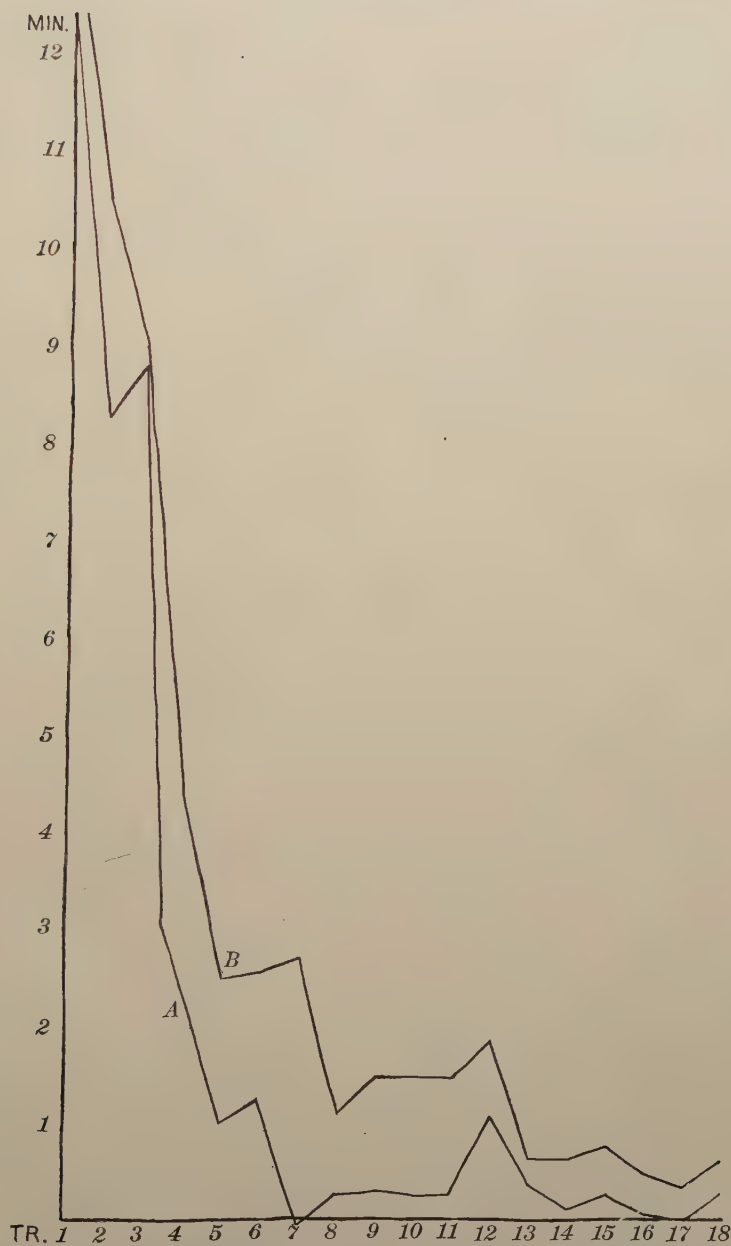


FIGURE 3—Curve A=difference between time curves in experiments with and without *cul de sacs* (Fig. 4); Curve B=error curve (see Fig. 2).

ing to the above assumptions, this curve should approximate the difference between the time and error curves, or the difference between this curve and the time curve should correspond closely to the error curve. This comparison is represented by

TABLE I
AVERAGE TIMES AND ERRORS FOR TWELVE RATS IN A MAZE WITH NO
CUL DE SACS

Trial	Time	Error	Trial	Time	Error
1.....	6.42	12.60	11.....	.44	.00
2.....	4.40	3.25	12.....	.30	.00
3.....	1.05	1.66	13.....	.30	.00
4.....	.84	.42	14.....	.33	.00
5.....	.45	.08	15.....	.29	.08
6.....	.39	.00	16.....	.29	.00
7.....	.78	4.50	17.....	.31	.00
8.....	.51	.25	18.....	.33	.16
9.....	.54	1.75	19.....	.24	.66
10.....	.46	.75	20.....	.27	.08

figure 3 in which B is the error curve and A is a curve representing the difference between the time values obtained on mazes with and without *cul de sacs*. No exact correspondence can be expected in the present case inasmuch as the maze used by the Misses Hybarger and Cowles is relatively simple in type and the error curve represents more than the mere elimination of blind alleys.

For the above reasons we are forced to conclude that for our conditions time is the best single criterion for an adequate representation of all features of the learning process.

In regard to the irregular variations, it is to be noted that it is the distance curve which presents the greatest uniformity and regularity of descent, and that there is very little difference between the time and error curves in this respect. These irregularities probably reflect peculiarities of behavior due to sex, age, individual characteristics, and disturbing conditions which can never be wholly eliminated with the best of technique. The instances of irregularity so often cited in the literature are isolated exceptional cases so pronounced as to attract attention. Certainly the variations exhibited by the curves are not so pronounced as one would expect from these instances. The explanation is probably to be found in the fact that these exceptional cases tend to be minimized by the law of averages consequent

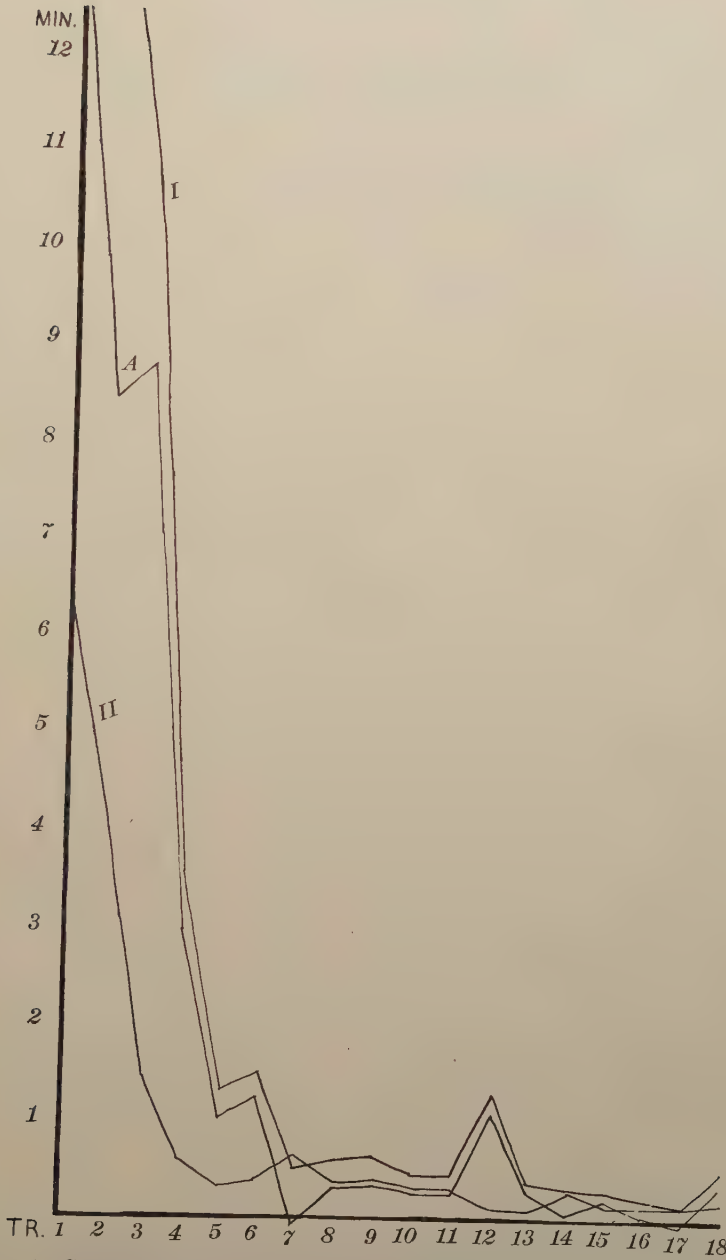


FIGURE 4—Curve I, time curve for seventeen rats in Hampton Court maze; Curve II, time curve for twelve rats in maze with no *cul de sacs*; Curve A, Curve I minus Curve II (see Fig. 3).

upon dealing with a large group of animals. However, the defect of irregularity cannot be urged against the time criterion any more than it can against that of error according to our results.

A curve combining the advantageous features of the time and error criteria may be urged for two reasons:—1st. While time does represent the fact of distance elimination, yet, inasmuch as the two are independent variables and independent to a considerable degree in the first stage of learning, it is evident that time cannot portray this eliminative process as adequately as the distance curve itself. 2nd. Probably one of the most important causes for the divergence of time and distance is the difference of behavior between species of animals. Obviously, such a factor is not operative in our experiment. That a choice of a criterion may depend upon the animal used was suggested in the first part of the paper. We have no experimental evidence in support of this contention. The peculiarities of behavior of the dancing mouse as opposed to that of the rat are apparently such as to demand a greater emphasis upon the distance criterion. If this conception be valid, it is evident that a combination curve constructed from the time and distance criteria will offer practical advantages for comparative purposes especially. Curve I of figure 5 represents a combination of time, error and distance in which each has been given an equal value. The error and distance curves, however, represent the same factor, so that a combination constructed on this basis gives too much importance to distance. Moreover, the distance criterion is impracticable for ordinary use. Hence we venture to suggest that the most practicable and the most representative curve for general comparative purposes will be obtained by a combination of the time and error criteria, provided that our standard of error unity is utilized. Such a combination is practically represented by curve II of figure 5, which gives half value to time and a quarter each to distance and error.

CONCLUSIONS.

The distance and error criteria are fundamentally alike, in that both represent the factor of distance elimination. The distance curve is the better representative of the progressive approximation of the act towards automatic accuracy. It

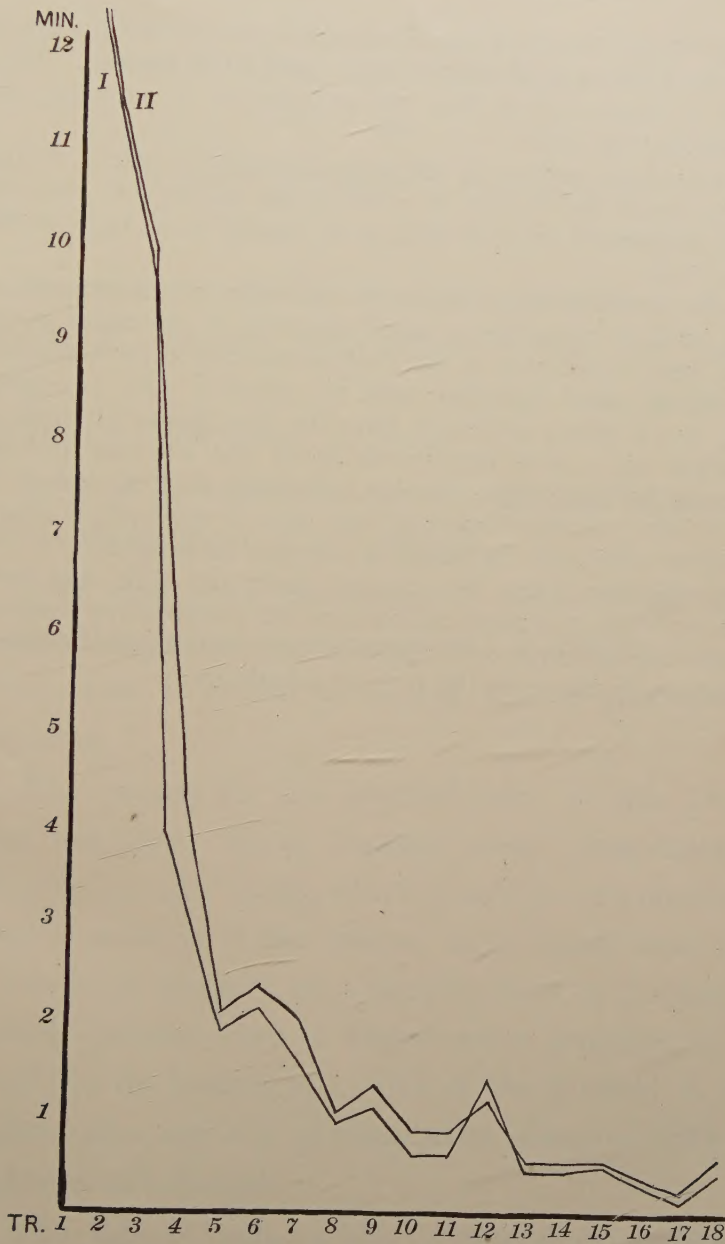


FIGURE 5—Curve I, combination curve for time, error, and distance—the three being given equal value; Curve II, combination curve for time (one-half value), error and distance (each one-quarter value).

portrays all the details of this eliminative process and it approximates the ideal of uniformity and regularity of descent. However, it is impracticable from the standpoint of recording and manipulating the data.

The prevalent practice of omitting all total and partial returns from the error record and of making no attempt to evaluate varying degrees of error gives a curve which is not only worthless but false.

An error curve which includes returns and which is constructed on the basis of regarding a small segment of the maze as the unit of error constitutes a practicable substitute for the excellencies of the total distance curve.

Any curve which portrays but the one factor of distance elimination is a poor representative of the learning process.

Time is the best single criterion, inasmuch as it represents all phases of the process of learning, and since it will yield the most comparable results at the hands of different investigators.

A combination curve constructed from the time and error data is probably the most satisfactory for comparative purposes provided the error record includes returns and a small segment of the maze is taken as the unit of calculation.

EDITORIAL ANNOUNCEMENT
OF
A DEPARTMENT OF NOTES

In order to provide for the publication of brief reports of valuable observations within the field of behavior, the Editors of the Journal have decided to establish a Department of Notes.

It is not intended that news items shall be presented in this Department of the Journal.

Any one who has facts of behavior to report, however fragmentary, incomplete, or unsystematic the observations, is invited to submit a brief description of the same.

The reasons for the establishment of this Department are two. First, because many observations of behavior, casually made, which would be of considerable value to students of the subject, now remain unrecorded by reason of the lack of a suitable place of publication. Second, because such a Department promises to add greatly to the interest and value of the Journal to those readers who are not professionally occupied with the problems of behavior.

The Editors wish, in this connection, to emphasize, the desirability of having the "experimental" studies in

behavior which are contributed to the Journal balanced by thoroughly scientific "naturalistic" studies.

It is hoped that the Department of Notes may encourage the recording of those infrequent, but highly important, acts of animals which the "experimentalist" has little chance of observing in the laboratory.